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ATTACHMENT 3

GEOSCIENCE

March 27, 2013

VIA E-MAIL AND U.S. MAIL

Mr. Richard C. Svindland, P.E.*
Vice President - Engineering
California American Water
4701 Beloit Drive
Sacramento, CA 95838
916.568.4296 (office)
916.204.2190 (cell)

Re: Slant Well Desalination Feedwater Supply System and Method for Constructing the Same - Notice of U.S. Patent No. 8,056,629 and U.S. Patent Publication No. 2012/0292012

Dear Rich:

We appreciate your confidence and thank you for selecting us to work with you on the Monterey Peninsula Water Supply Project.

We have informed RBF Consulting that GEOSCIENCE Support Services, Inc. ("GSSI") owns several U.S. patents and published patent applications. I write to specifically bring to your attention GSSI's recently issued U.S. Patent No. 8,056,629, titled "Slant Well Desalination Feedwater Supply System and Method for Constructing Same" and GSSI's recently published U.S. Patent Application Publication No. 2012/0292012, titled "Desalination Subsurface Feedwater Supply and Brine Disposal." This patent and patent application publication are pertinent to the test slant and observation wells that GSSI will be designing for you. Copies of this patent and patent application publication are enclosed for your reference.

Please note that all intellectual property of GSSI, including without limitation the patent and patent application publication mentioned above, will at all times remain the sole property of GSSI. No assignment or license of any inventions, patents, copyrights, trademarks, trade secrets, or other intellectual property rights, or applications for same, is granted or conveyed to you. If you have any questions, please do not hesitate to contact me.

Sincerely,

Meridee E. Williams

SMRH:408073253.1
Encl.: U.S. Patent No. 8,056,629 and U.S. Patent Application Publication No. 2012/0292012
cc: Mr. Paul Findlay/RBF Consulting

GEOSCIENCE SUPPORT SERVICES INCORPORATED
Ground Water Resources Development
P.O. Box 220, Claremont, CA 91711
FAX 909-451-6638
909-451-6650

U.S. PATENT DOCUMENTS

5,771,976	A *	6/1998	Talley	166/370
6,073,659	A *	6/2000	Lange	138/177
6,422,318	B1 *	7/2002	Rider	166/380
6,581,683	B2 *	6/2003	Ohanesian	166/236
6,581,688	B2 *	6/2003	Voll et al.	166/278
7,118,307	B2	10/2006	Stoecker et al.	
7,322,422	B2 *	1/2008	Patel	166/387
7,654,343	B2 *	2/2010	Snow	175/61
7,699,557	B2 *	4/2010	Shaw et al.	404/2
2001/0047865	A1 *	12/2001	Voll et al.	166/250.14
2002/0033266	A1 *	3/2002	Hester et al.	166/369
2002/0189809	A1 *	12/2002	Nguyen et al.	166/278
2006/0260795	A1 *	11/2006	Rescia	166/51
2008/0142227	A1 *	6/2008	Yeh et al.	166/369
2009/0008092	A1 *	1/2009	Haeberle et al.	166/278
2009/0178801	A1 *	7/2009	Nguyen et al.	166/249
2009/0241685	A1 *	10/2009	Charette	73/861.07
2011/0162850	A1 *	7/2011	Williams	166/369

OTHER PUBLICATIONS

Gary Smith, A New Angle on Well Construction, Approximately 2005.

Dennis E. Williams, The Use of Wells to Provide Water for Seawater Desalination Systems, 15th Annual GRA Meeting and Conference, San Diego, California, Sep. 22, 2006.

Dennis E. Williams, Use of Low Angled Wells for Desalinaton Feedwater Systems, ASCE Hydrology & Hydraulics Committee Meeting & Presentation, Aug. 28, 2007.

Dennis E. Williams, Radial Wells, The Encyclopedia of Water, John Wiley and Sons, 2005.

Mr. Richard Bell, P.E. and Dennis Williams, Ph.D.—Overview of the Dana Point Ocean Desalination Project, May 14, 2008.

Dennis E. Williams, Slant Well Installed and Tested in Dana Point, California, Horizontal News, Summer 2007, vol. 10, No. 1 National Ground Water Association.

Dennis E. Williams, Results of Drilling, Construction, Development and Testing of Dana Point Ocean Desalination Project Test Slant Well, Horizontal News, Summer 2007, vol. 10, No. 1, National Ground Water Association.

California: SoCal SWRO Study Presented, Water Desalination Report, May 18, 2009, vol. 45, No. 19, Media Analytics.

South Coast Coastal Ocean Desalination Project Update, Laguna County Water District—Waves, Jan./Feb. 2009, vol. 5, Issue 1.

Municipal Water District of Orange County, Dana Point Ocean Desalination Project, Project Overview, Apr. 2007.

* cited by examiner

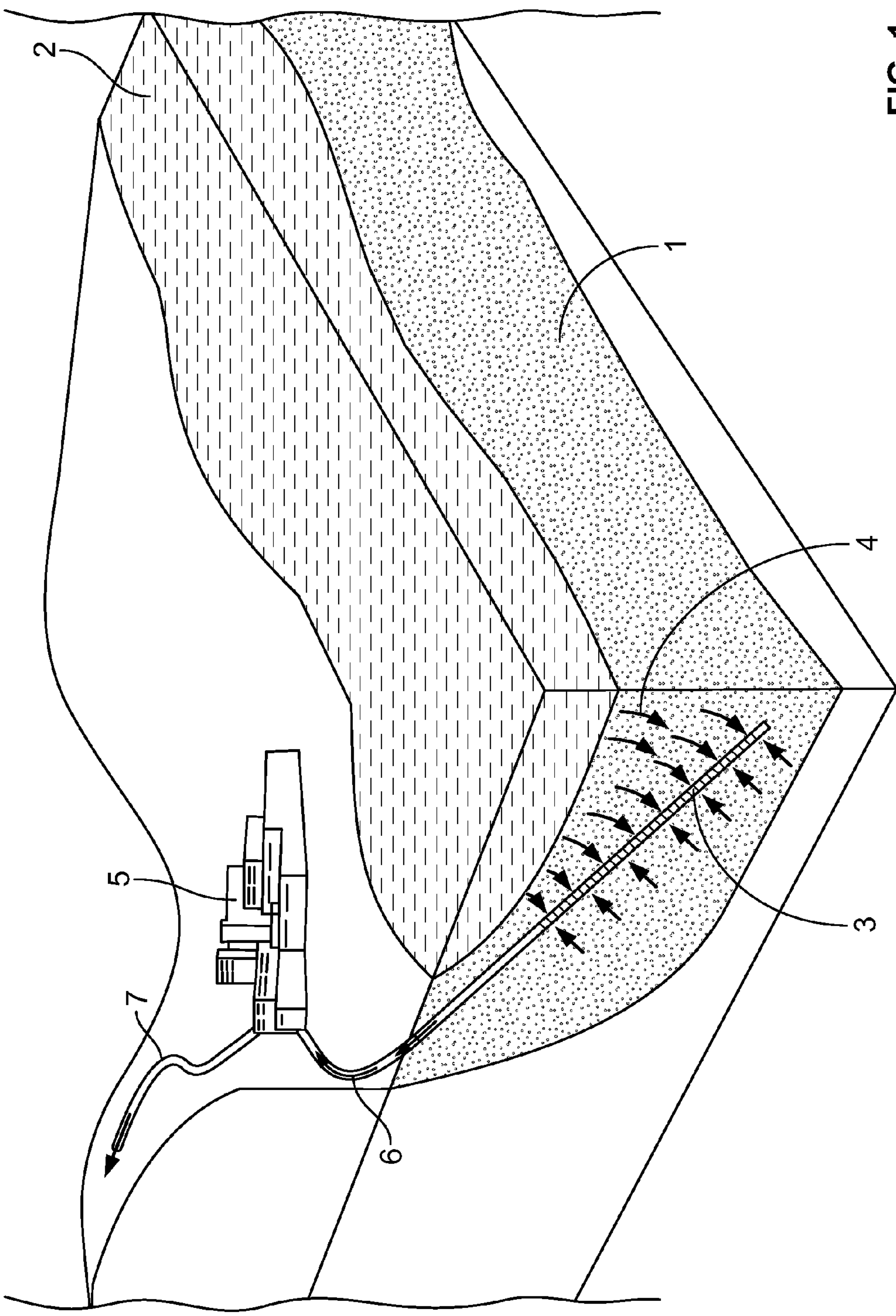


FIG. 1

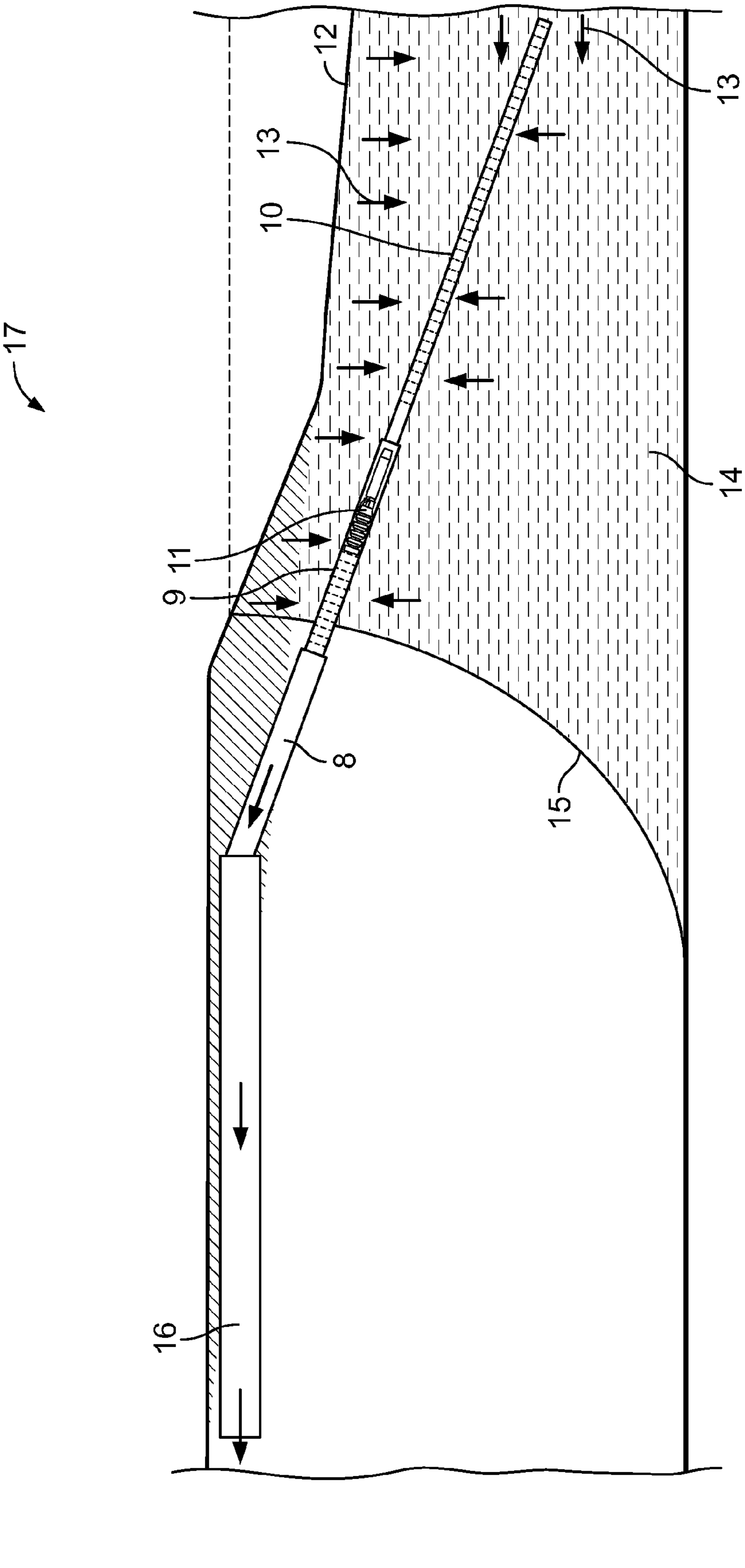


FIG. 2

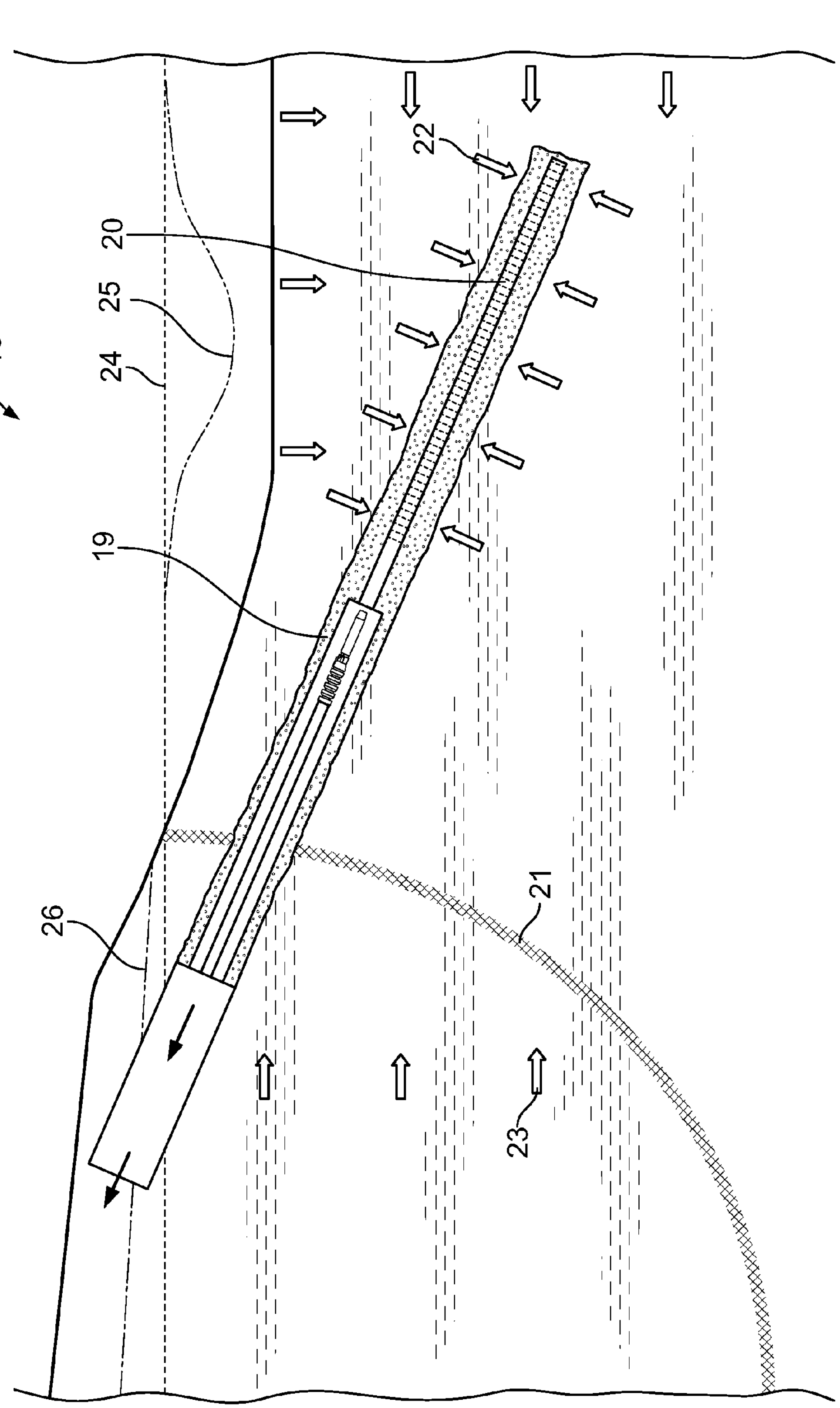


FIG. 3

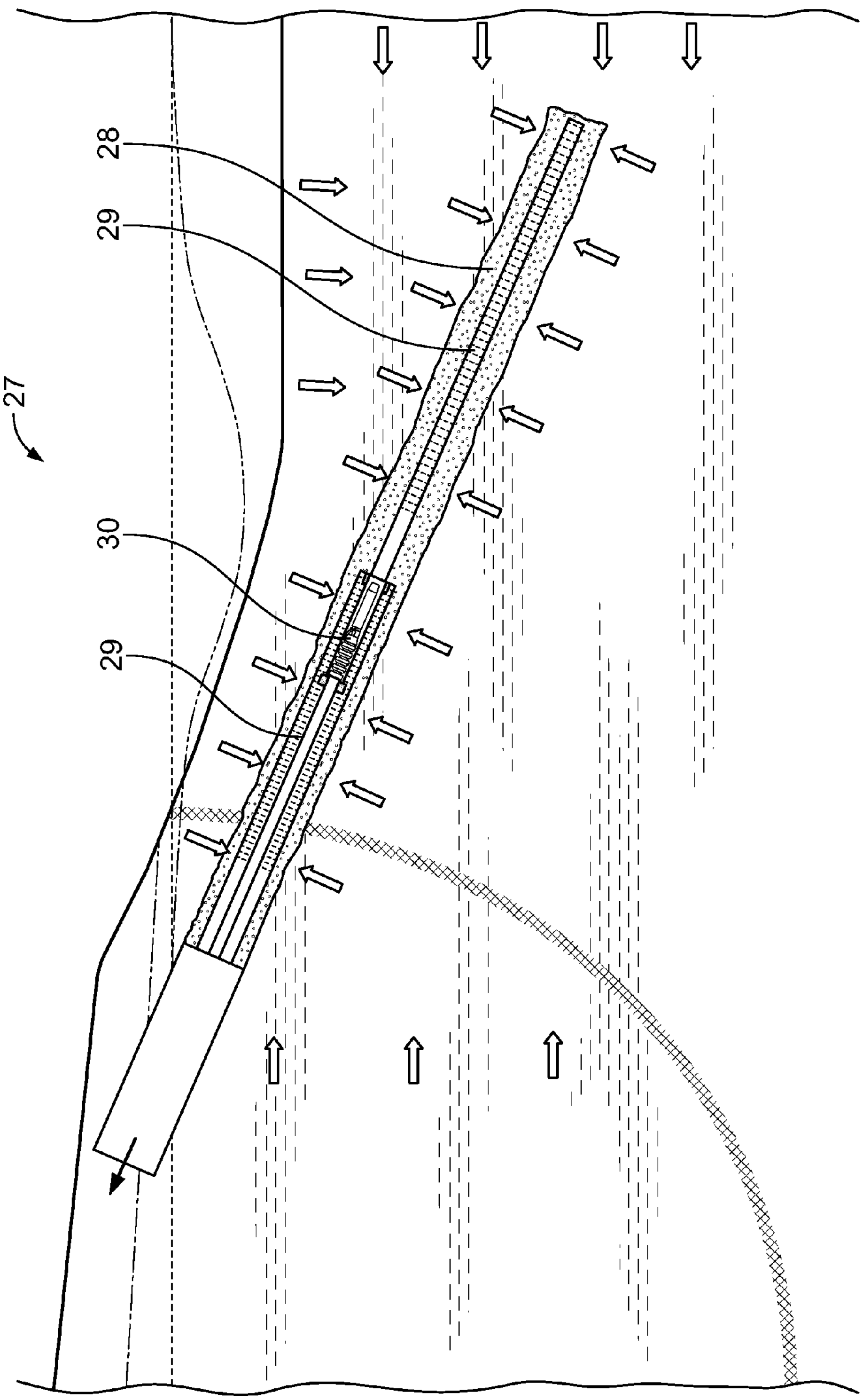


FIG. 4

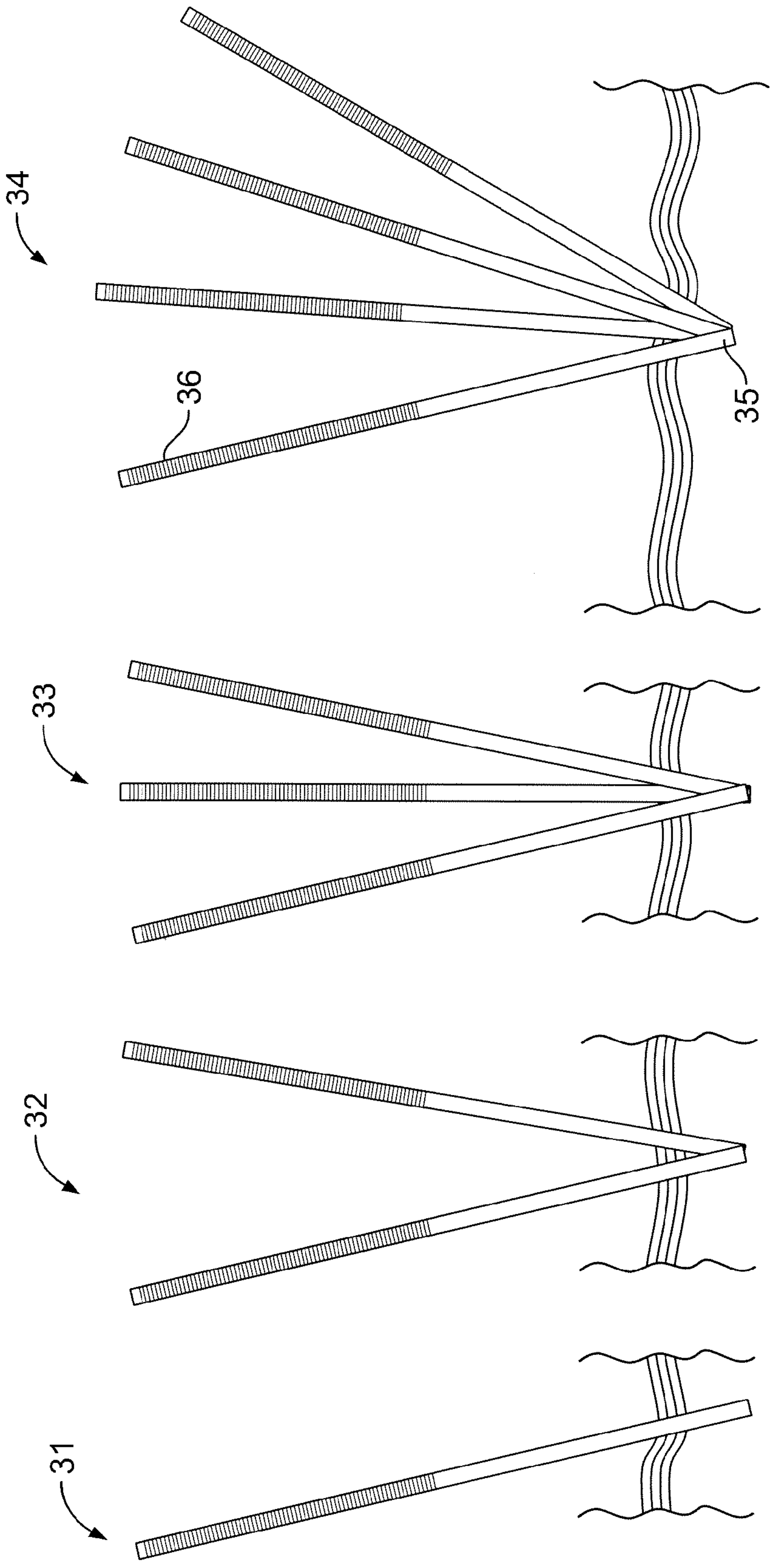


FIG. 5D

FIG. 5C

FIG. 5B

FIG. 5A

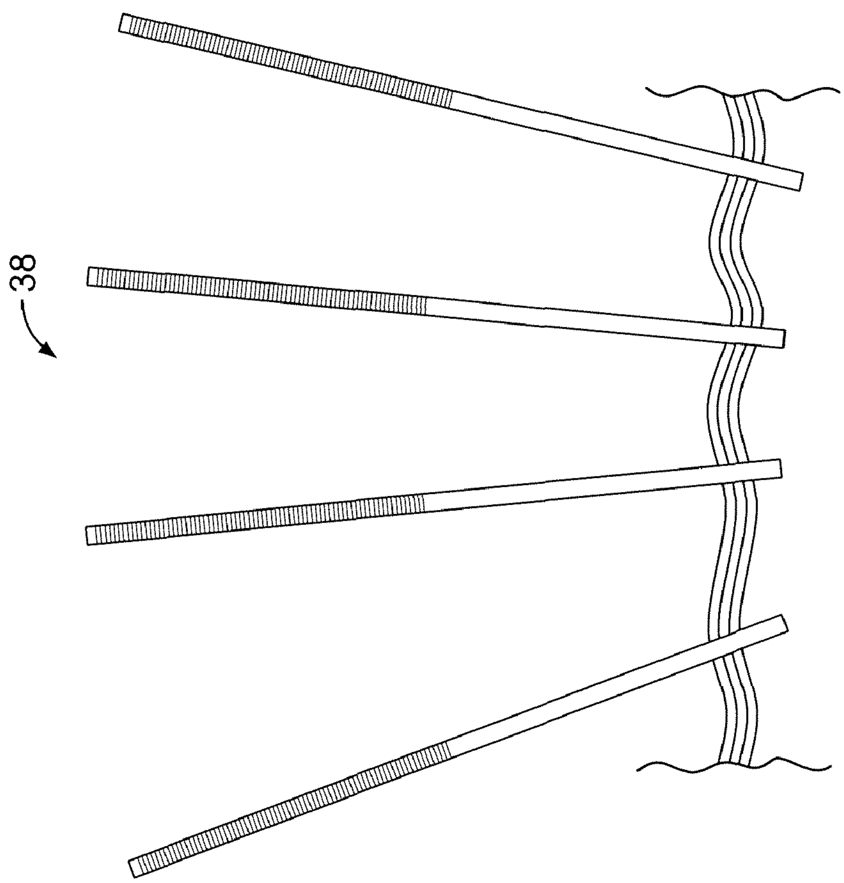


FIG. 6B

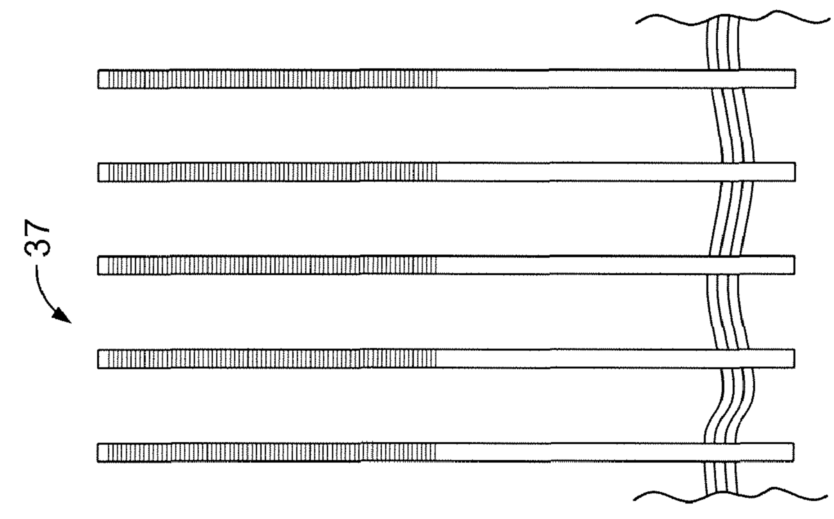


FIG. 6A

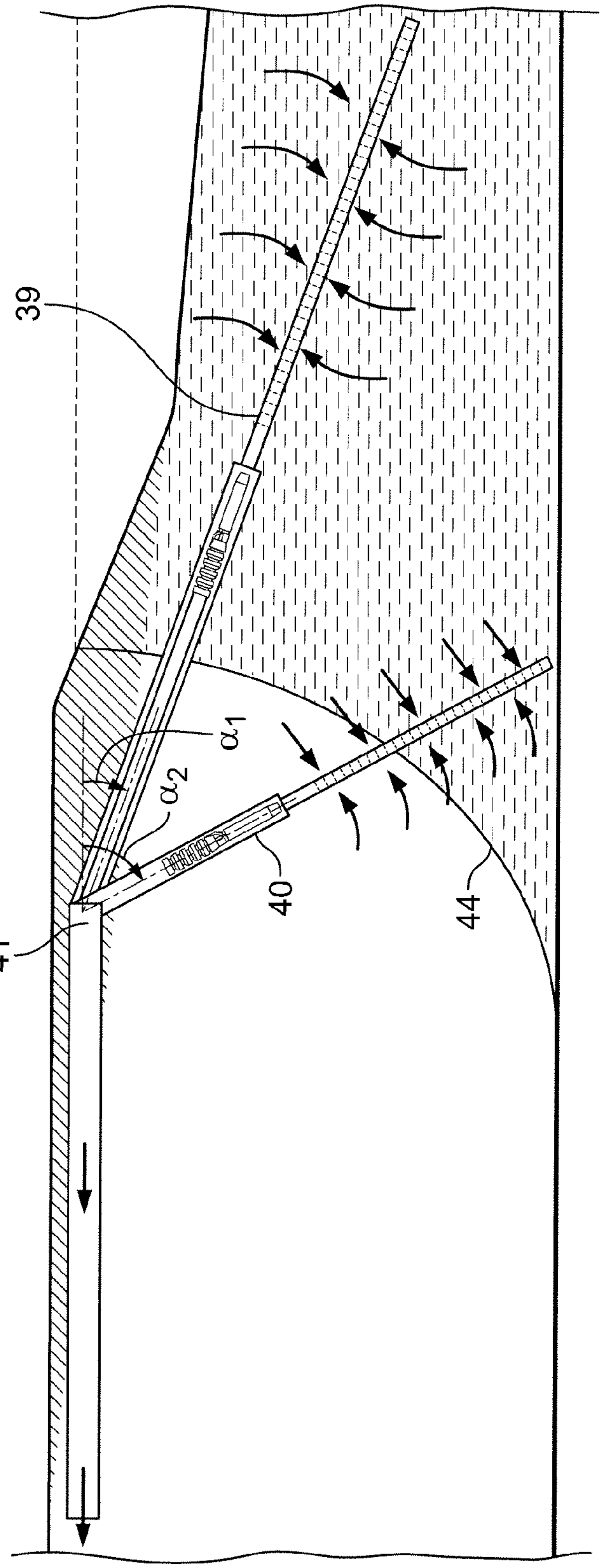


FIG. 7

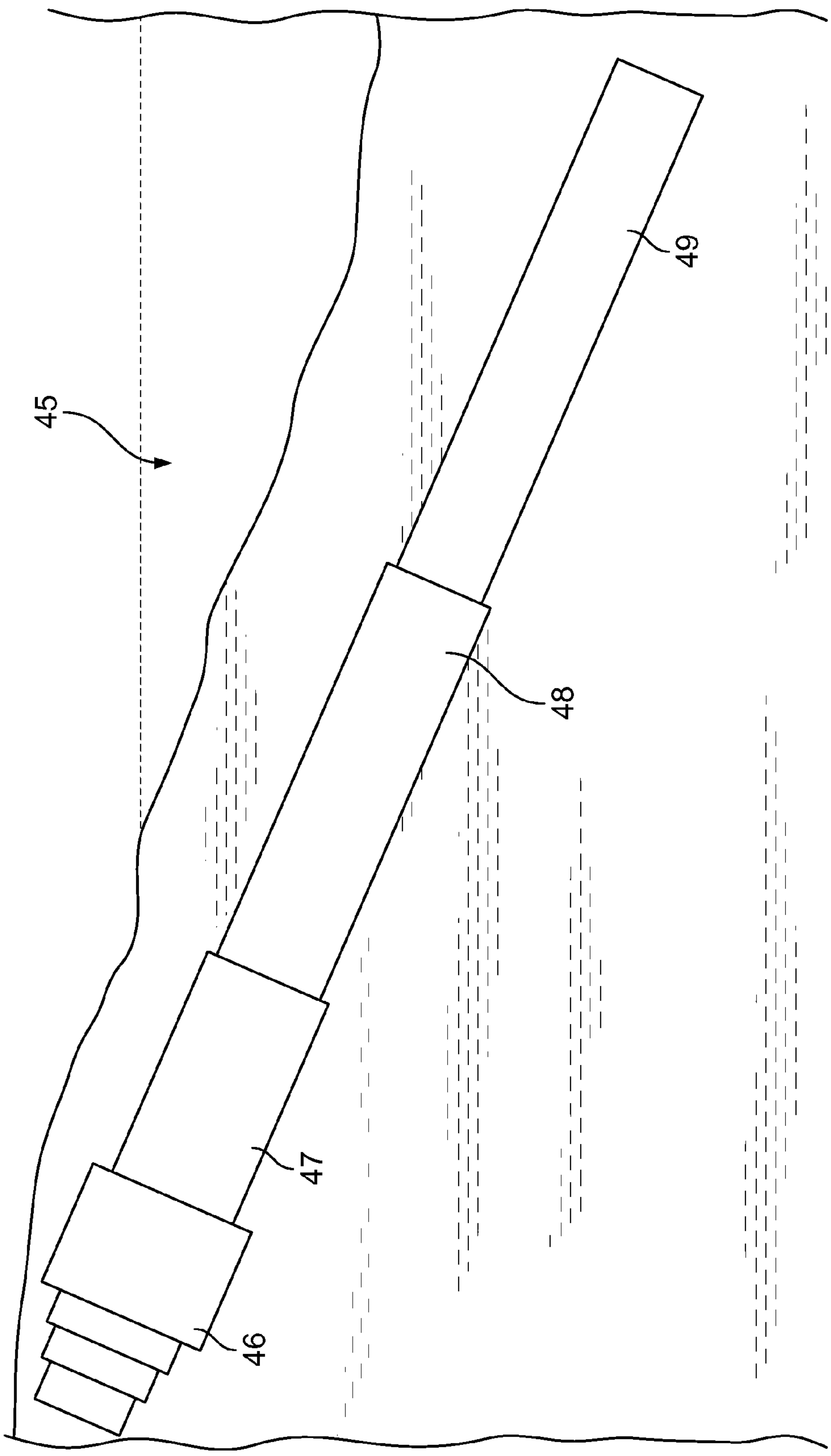


FIG. 8

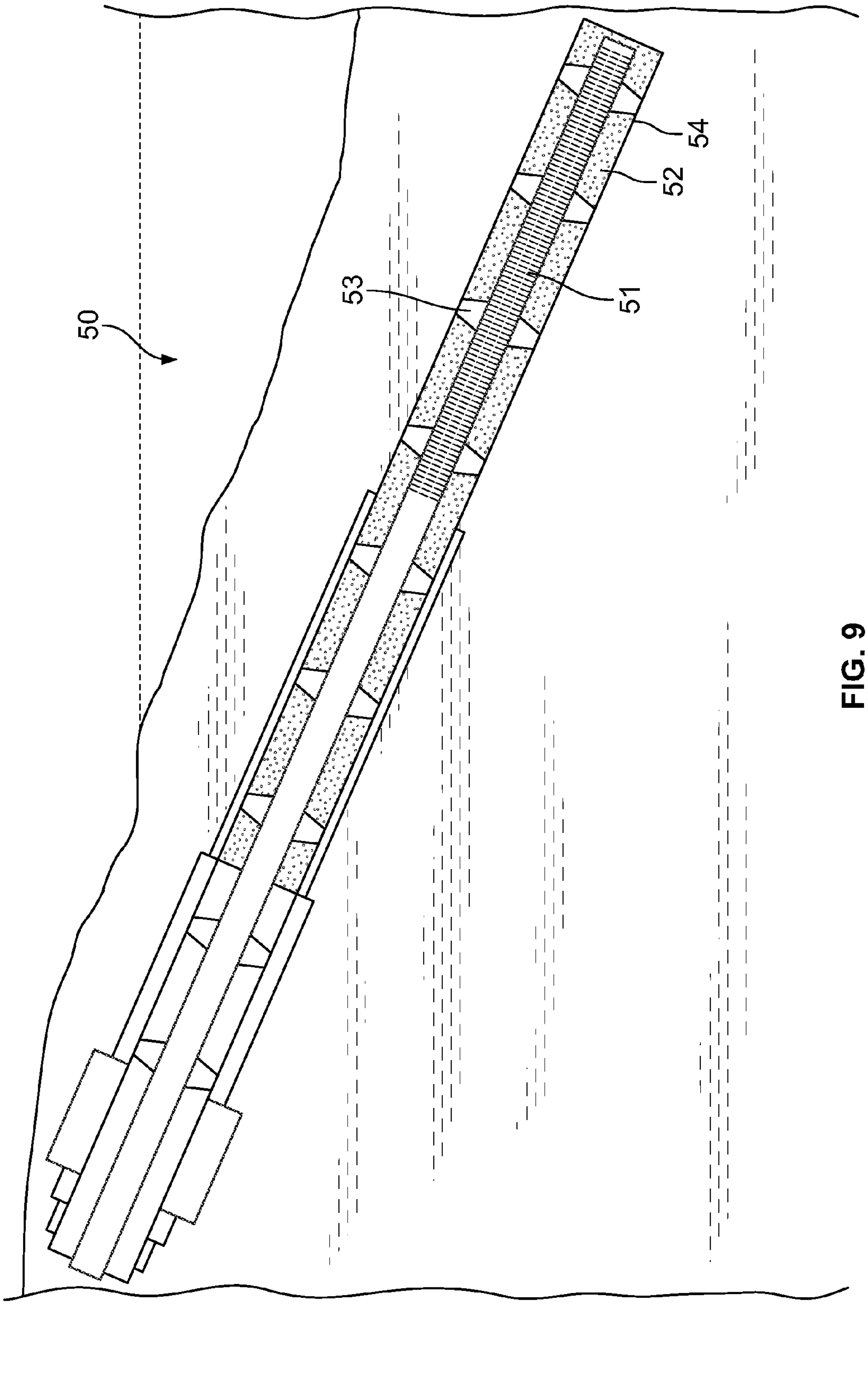


FIG. 9

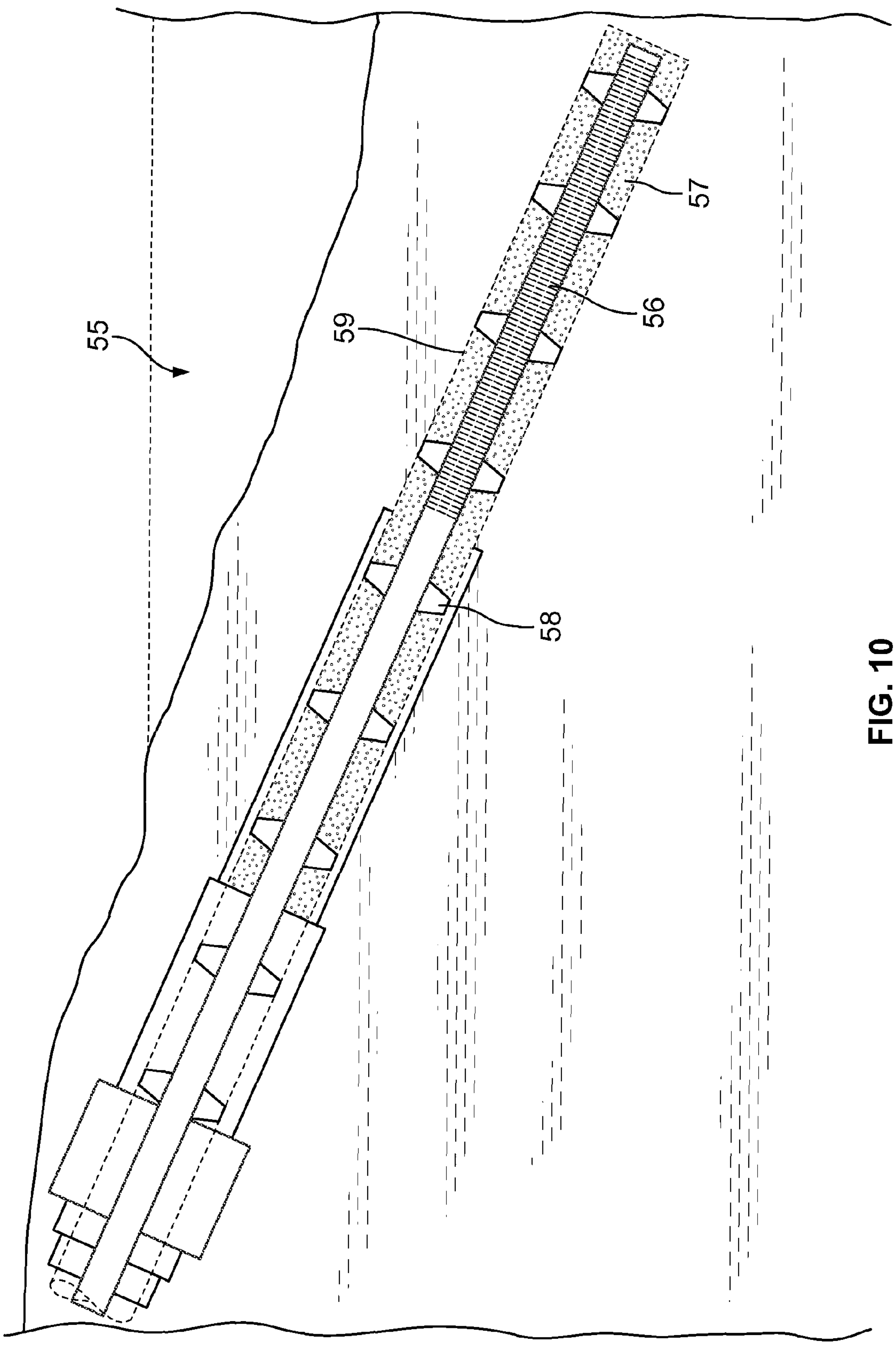


FIG. 10

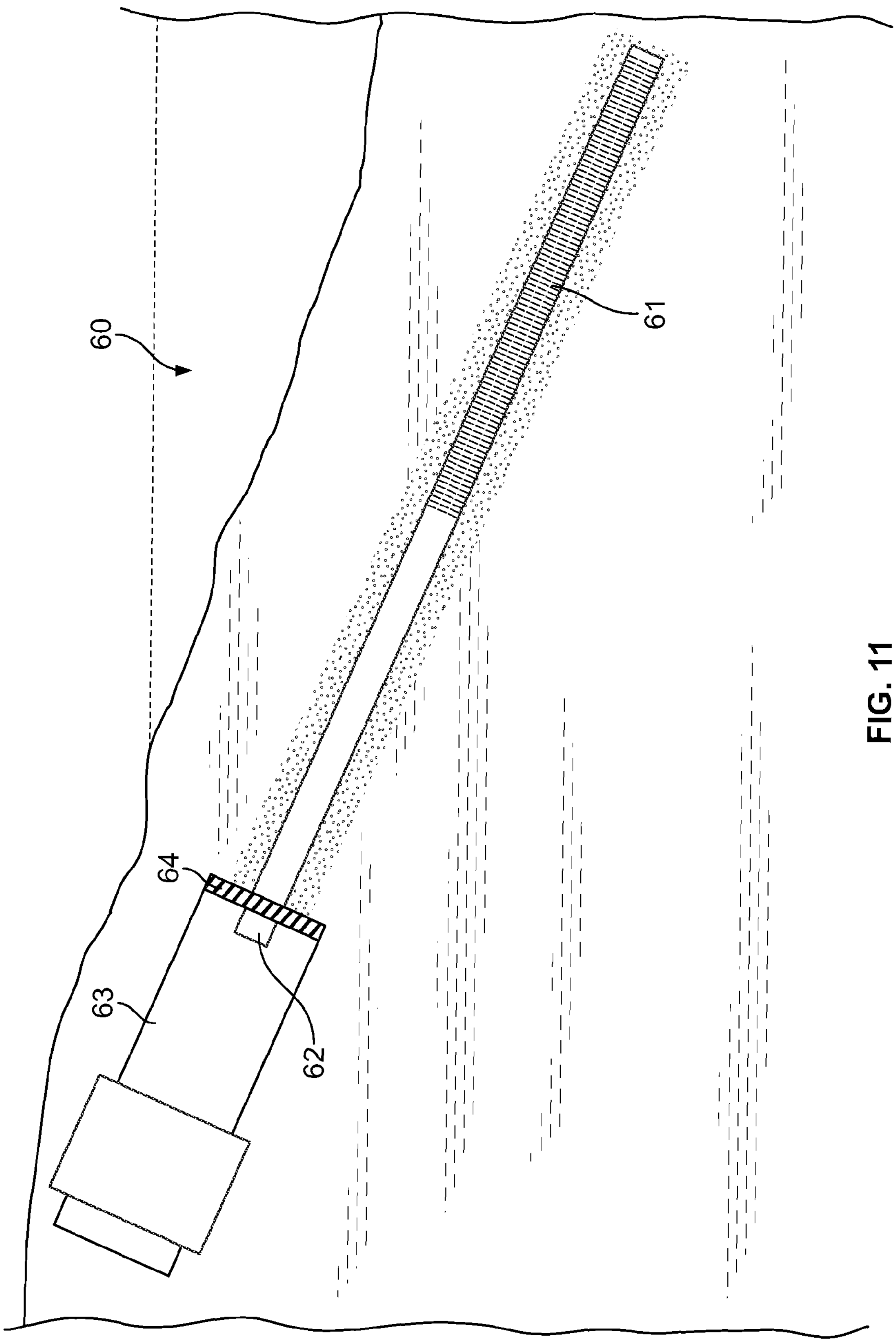


FIG. 11

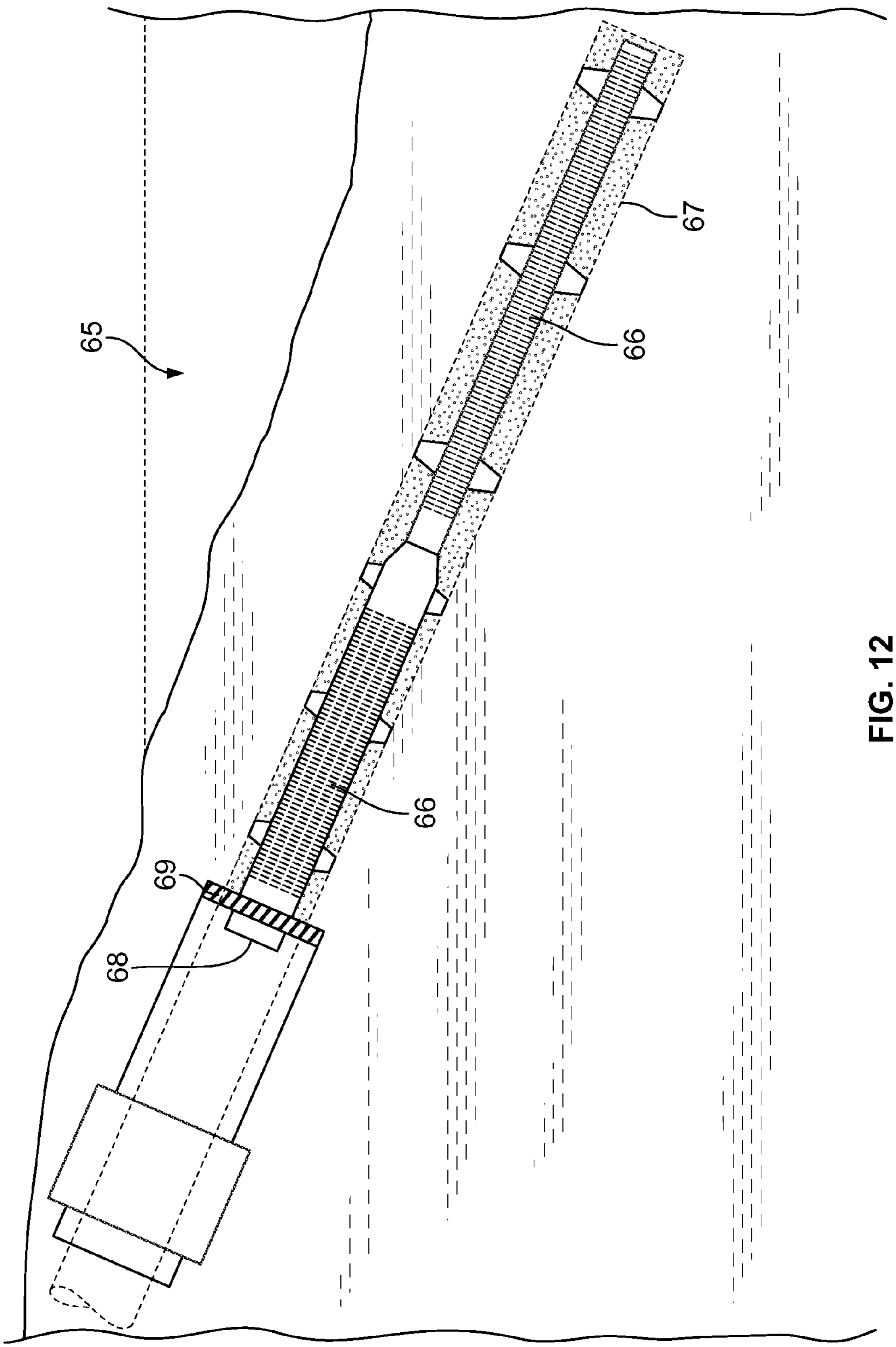


FIG. 12

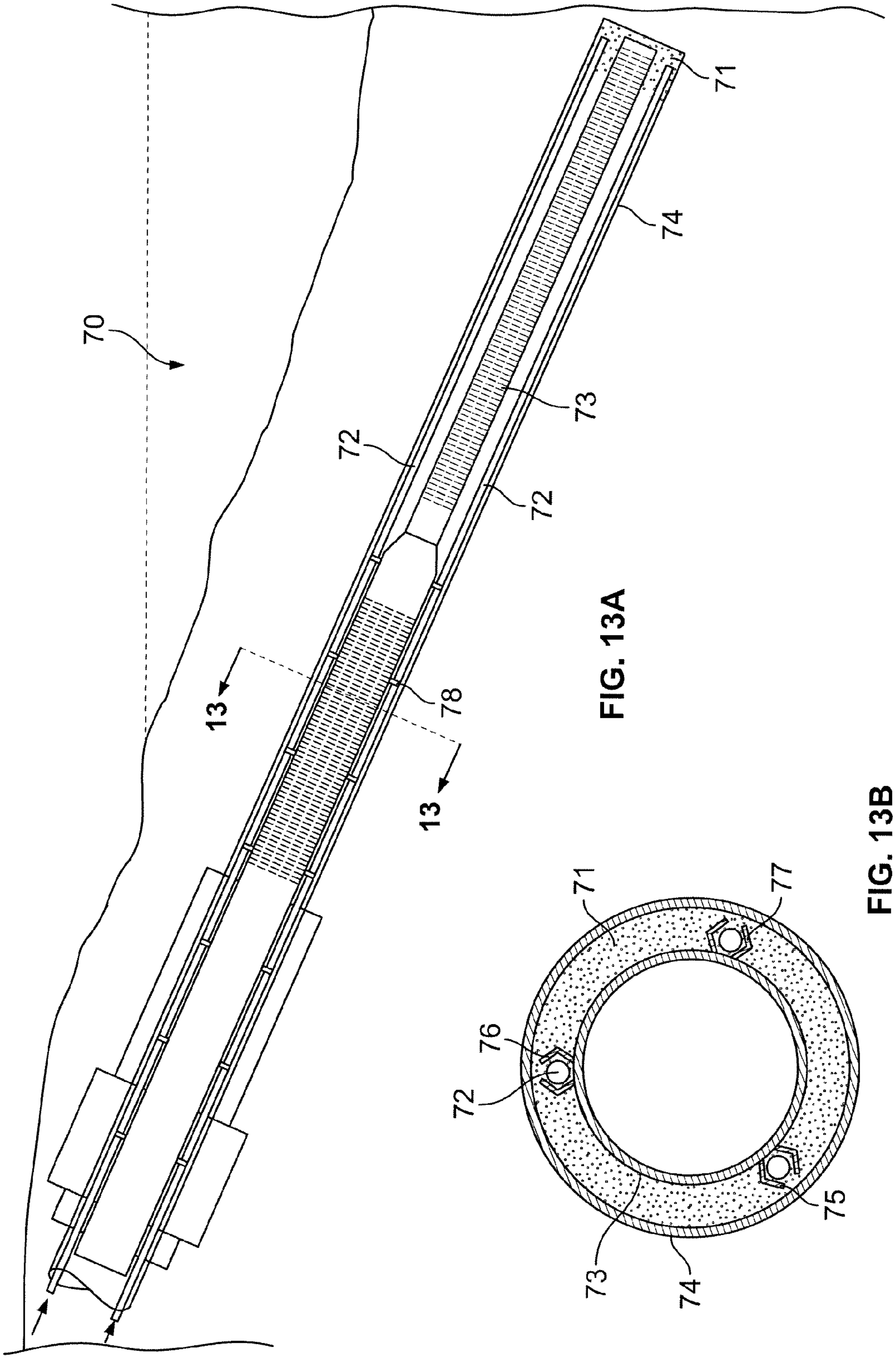


FIG. 13A

FIG. 13B

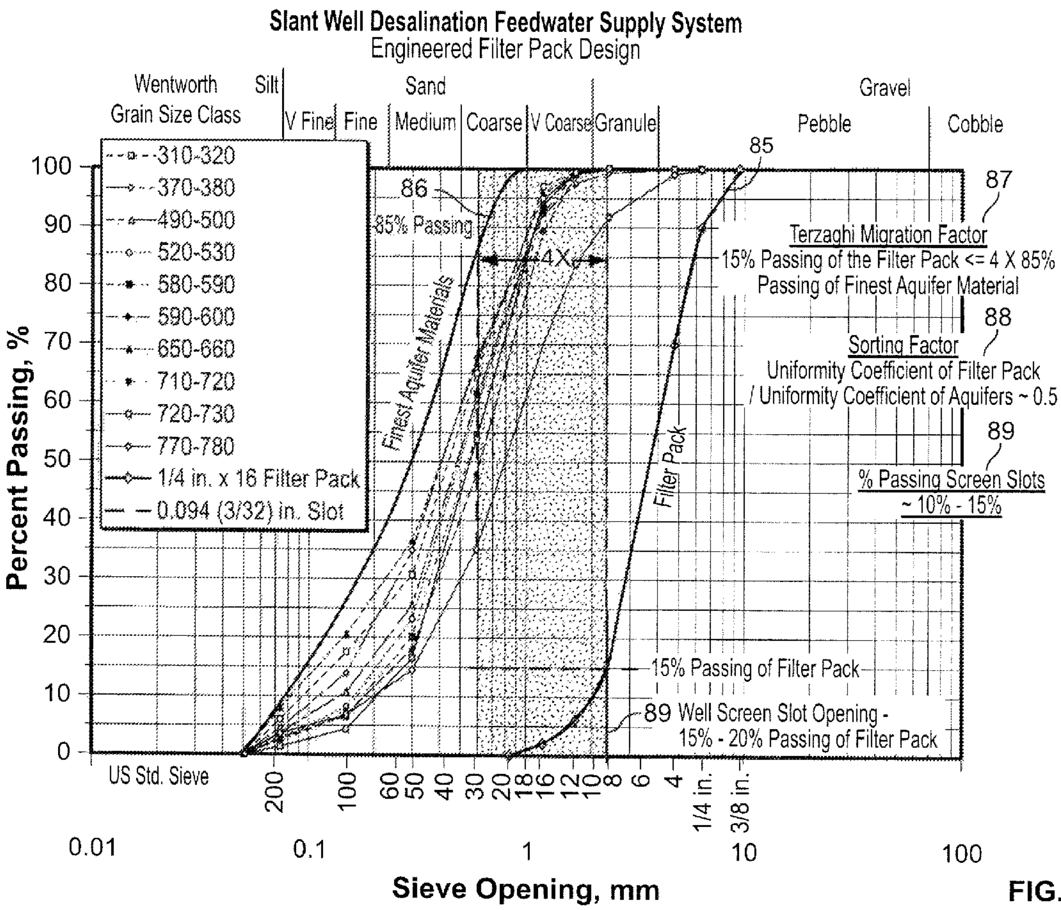

Slant Well Desalination Feedwater Supply System
Engineered Filter Pack Design
Wentworth Grain Size Class
Silt
Sand
V Fine
Fine
Medium
Coarse
V Coarse
Granule
Gravel
Pebble
Cobble
310-320
370-380
490-500
520-530
580-590
590-600
650-660
710-720
720-730
770-780
1/4 in. x 16 Filter Pack
0.094 (3/32) in. Slot
86
85% Passing
4X
85
87
Terzaghi Migration Factor
15% Passing of the Filter Pack <= 4 X 85% Passing of Finest Aquifer Material
88
Sorting Factor
Uniformity Coefficient of Filter Pack / Uniformity Coefficient of Aquifers ~ 0.5
89
% Passing Screen Slots ~ 10% - 15%
Finest Aquifer Materials
Filter Pack
15% Passing of Filter Pack
89 Well Screen Slot Opening - 15% - 20% Passing of Filter Pack
Percent Passing, %
US Std. Sieve
200
100
60
50
40
30
20
18
16
12
10
8
6
4
1/4 in.
3/8 in.
0.01
0.1
1
10
100
Sieve Opening, mm

FIG. 15

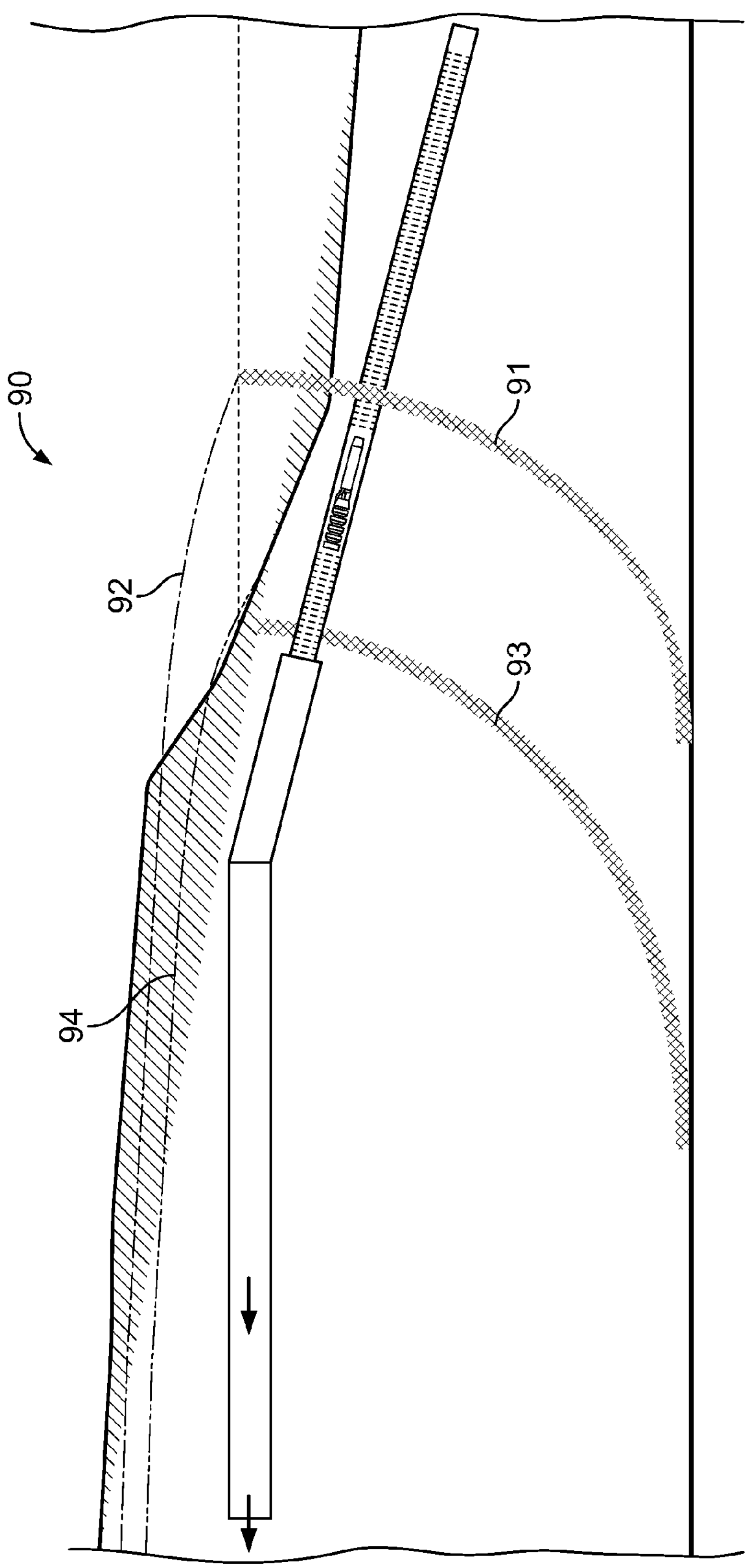


FIG. 16

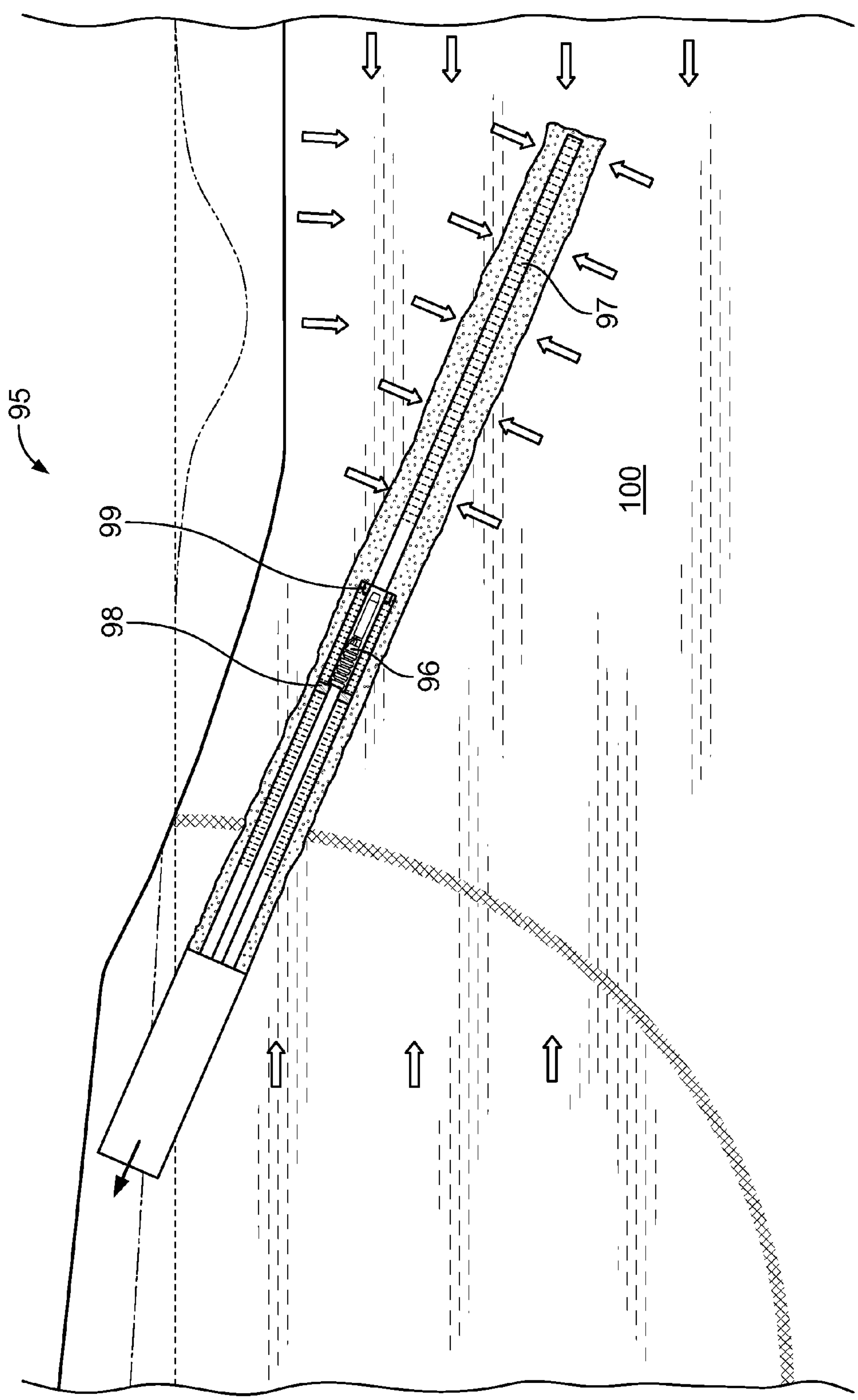


FIG. 17

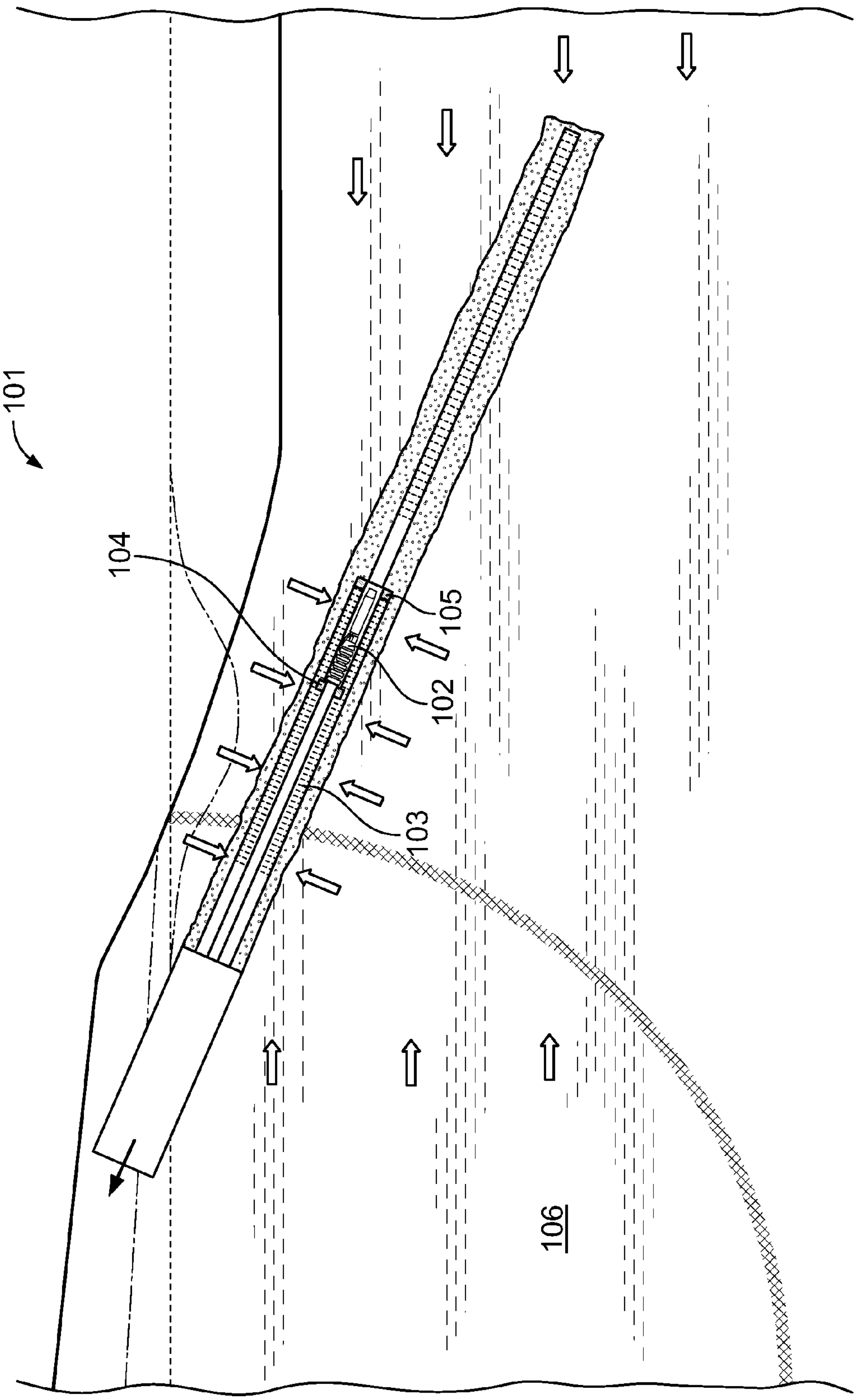


FIG. 18

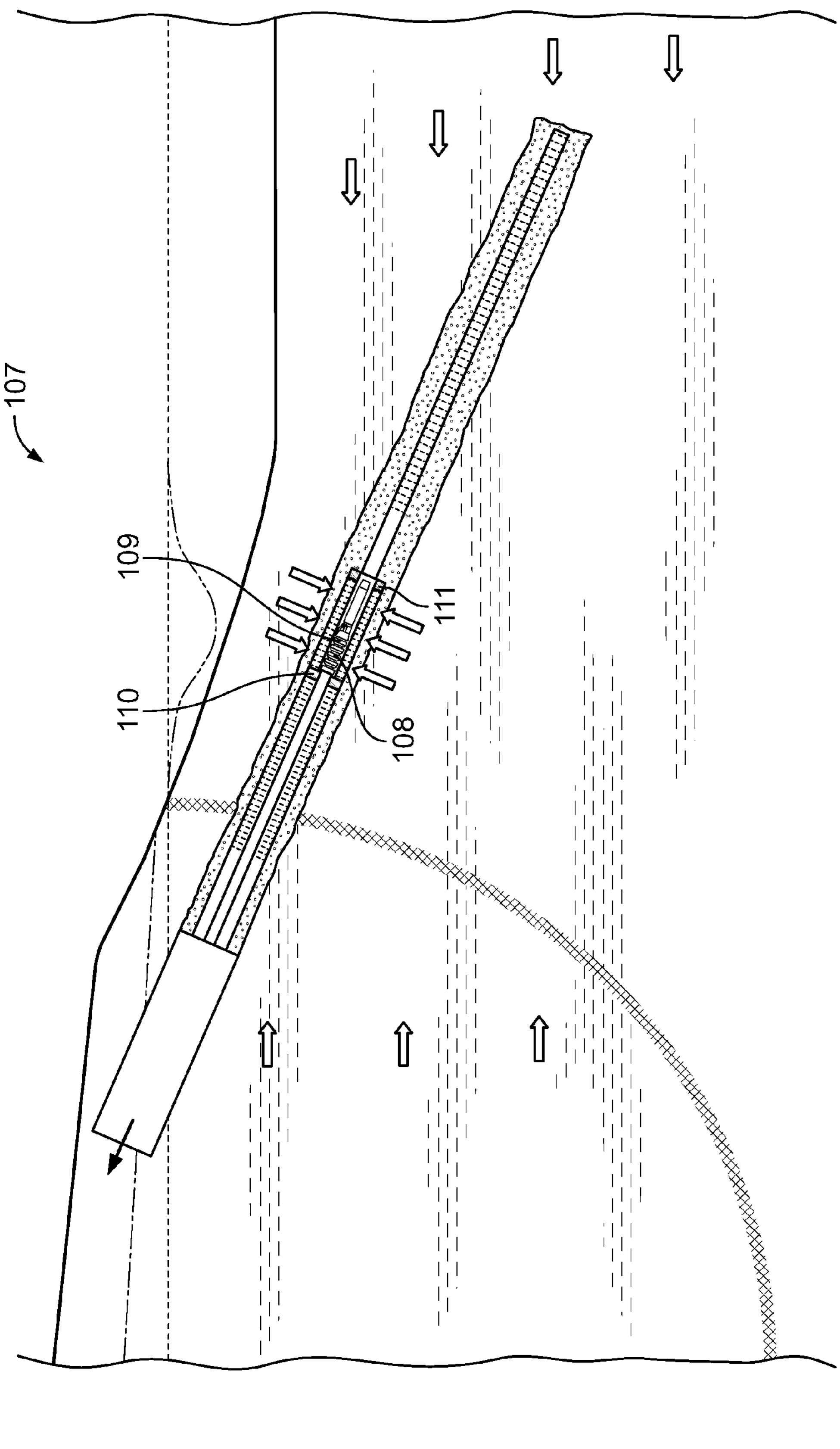


FIG. 19

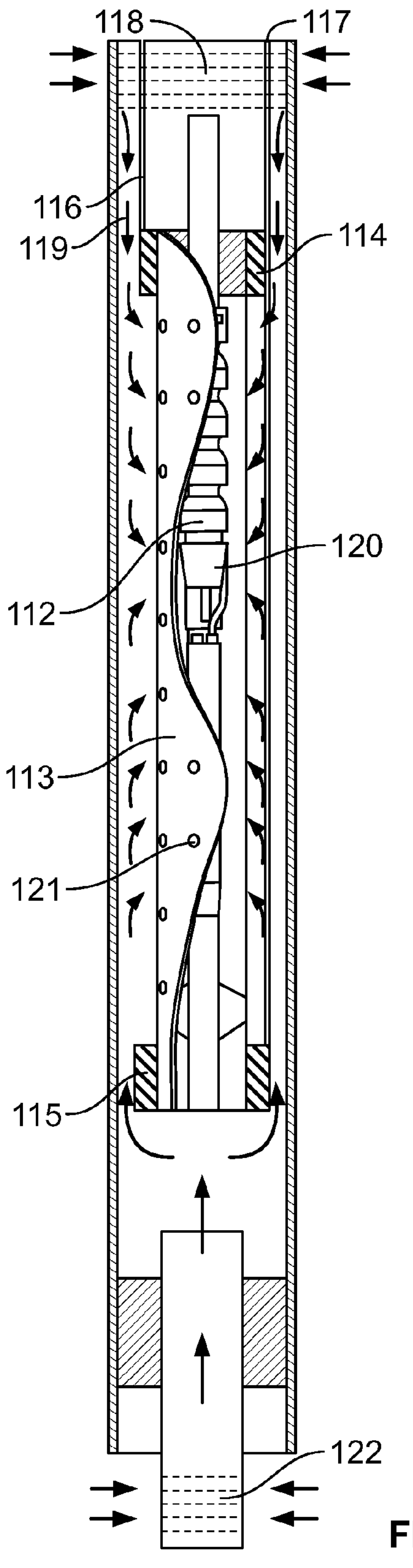


FIG. 20

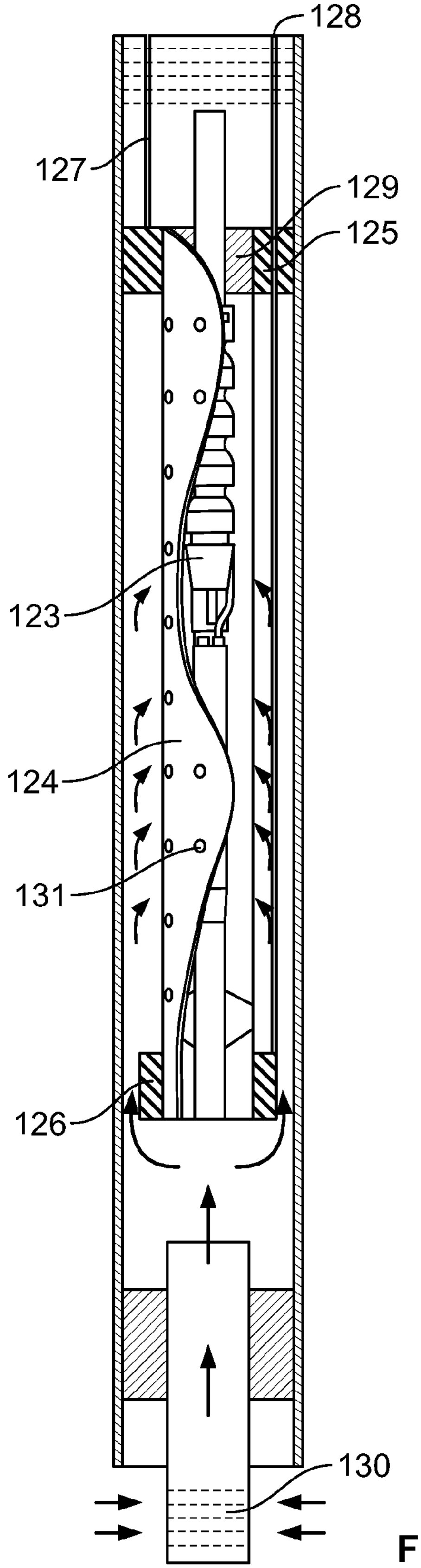


FIG. 21

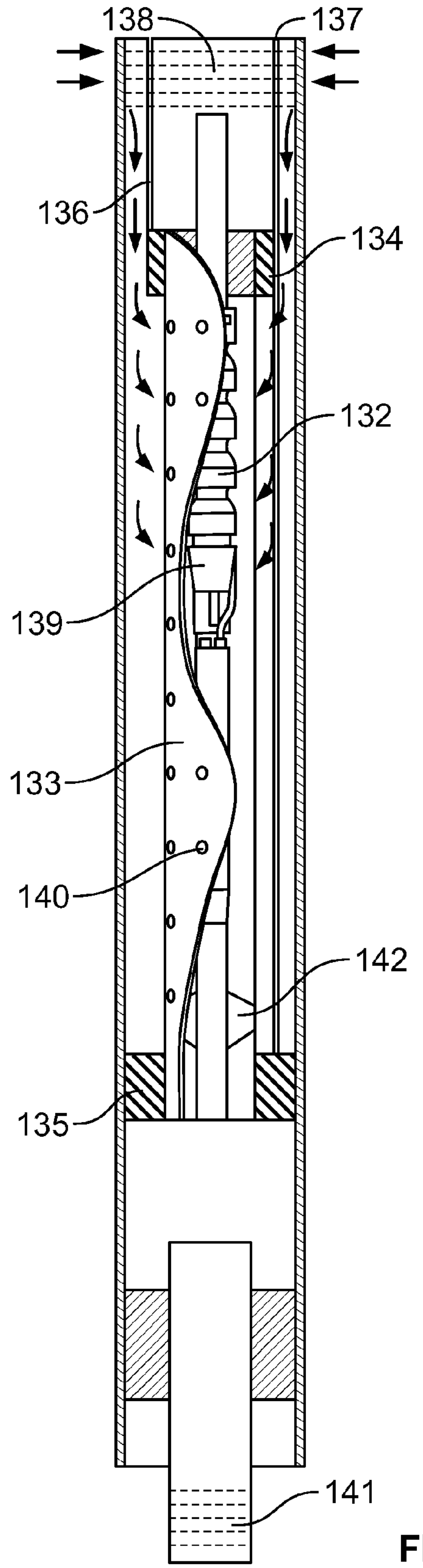


FIG. 22

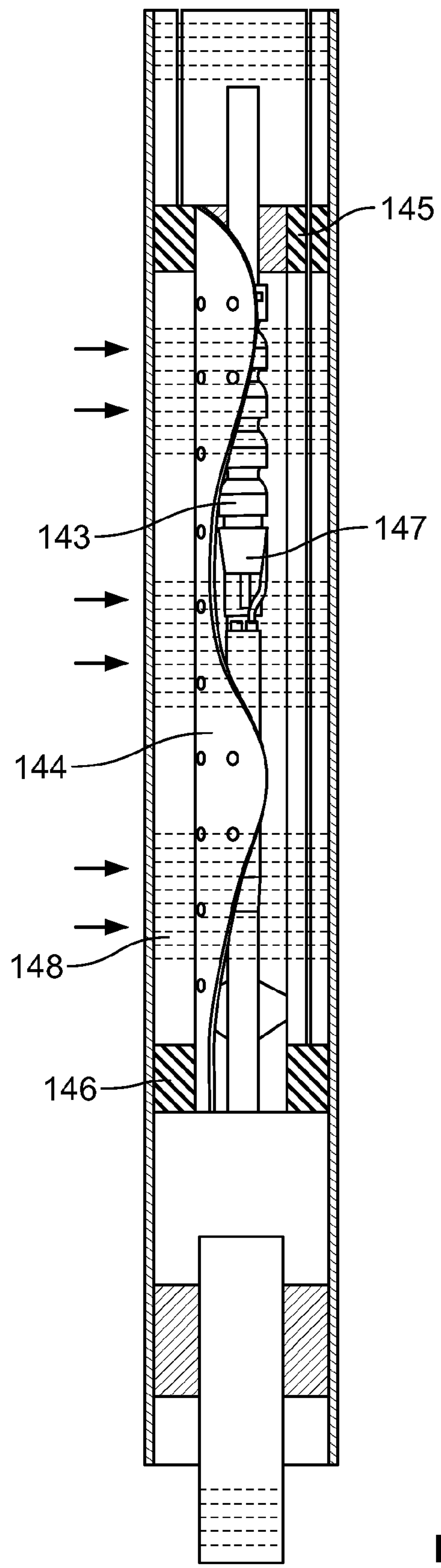


FIG. 23

SLANT WELL DESALINATION FEEDWATER SUPPLY SYSTEM AND METHOD FOR CONSTRUCTING SAME

CROSS-REFERENCE TO RELATED APPLICATION

Priority is claimed under 35 U.S.C. §1.19(e) to U.S. Provisional Application No. 61/293,134, filed by Dennis E. Williams on Jan. 7, 2010 and entitled "Slant Well Desalination Feedwater Supply System." This application is incorporated by reference herein.

FIELD OF THE INVENTION

The invention relates generally to the field of supplying water from subsurface intake systems to desalination plants. More specifically, the invention relates to the construction of slant well systems to supply water from near-shore or subsea aquifers to desalination plants.

BACKGROUND OF THE INVENTION

Water developers in California and other coastal communities throughout the world are increasingly considering seawater desalination as a potential source of water for municipal and industrial supply. Limited ground water supplies in the coastal areas, poor inland ground water quality, and decreasing reliability of imported water have made seawater desalination a viable consideration. Seawater desalination has been made even more viable through more cost-effective and efficient subsurface intake systems and water treatment technologies.

Slant well drilling is included in the practice of drilling non-vertical wells. Non-vertical wells are typically used in the petroleum industry and are also known as horizontally directionally drilled wells (HDD wells). Slant wells are also used in other applications, such as drilling beneath roadways or rivers in order to provide conduits for facilities. Slant well desalination subsurface intake systems present significant advantages over traditional open water desalination plant intakes. These advantages include avoidance of entrainment and impingement impacts to marine life, reduction or elimination of costly reverse osmosis pretreatment, and reduction or elimination of permanent visual impacts. Slant well systems are buried systems (i.e. there are little or no visual impacts on the surface), as the wells and connecting pipelines are typically completed below the land surface.

In the past, slant well technology has not been successfully applied to subsea construction of desalination feedwater supplies, as the well screen slots have become clogged during pumping. Once the well screen slot openings are clogged, it becomes difficult or impossible to continue to pump water. Accordingly, there is a need for a reliable slant well system that is able to supply water from near-shore or subsea aquifers to a desalination plant without becoming clogged with fine-grained materials (e.g., fine sands and silts) over time. There is also a need for a method of constructing such a system—especially at low angles below horizontal in order to minimize impacts to inland fresh water sources. The present invention satisfies these needs and provides further related advantages, especially with regard to regulation of feedwater salinity.

SUMMARY OF THE INVENTION

The present invention is embodied in a system for supplying water to a desalination plant from a subsurface feedwater

supply using one or more slant wells. The present invention is also embodied in a method for constructing a slant well feedwater supply system for supplying water from a subsurface feedwater supply. A system of angled wells (slant wells) is constructed. In one embodiment, the slant wells obtain a desalination feedwater supply from permeable aquifer systems near and/or beneath a saline water source (i.e., an ocean, sea, or salty inland lake). The slant wells induce recharge of the aquifer system through the floor of the ocean, sea, or inland lake due to the hydraulic head difference between the slant well pumping level and the level of the ocean, sea, or lake. As the supply source is relatively constant, the water supply to such a slant well system generally provides a long-term, sustainable water source for a desalination plant. The slant wells may be constructed at angles that vary from zero to ninety degrees below horizontal.

In one embodiment, the systems and methods discussed here are different from other non-vertical well applications in that they include an engineered, artificially filter-packed, angled well designed specifically to produce a high-capacity, low-turbidity desalination plant feedwater supply source from near-shore and offshore subsurface aquifer systems.

In one embodiment of the invention, the slant wells include a unique telescoping set of casings and screens. This design allows for a larger pump house casing near the land surface, with successively smaller casing and screen diameters as the well extends downward. The telescoping casings and screens facilitate extending the well to lineal lengths of 1,000 feet or greater beneath the floor of the saline water body, with angles below horizontal ranging from zero to ninety degrees.

In other, more detailed features of the invention, the slant well feedwater supply system may comprise a single slant well, an array of two or more slant wells, or multiple arrays of two or more slant wells, the location, spacing, and geometric layout of which may vary among feedwater intake sites depending upon the geohydrologic extent (horizontal and vertical) and characteristics of the subsurface aquifer materials, as well as upon the subsurface aquifer system salinity variation.

In another embodiment of the invention, an engineered artificial filter pack is placed around the well screen portions of the slant wells through a multi-step process that includes:

a. Placing the artificial filter pack in the annular space between the well screen and a temporary casing by pumping the filter pack material under pressure through one or more movable tremie pipes;

Placing a movable packer assembly within the bore of the well screen section near the portion of the well where the artificial filter pack is being placed;

c. Pumping water through the center of the well-screen packer assembly so that the water exits the well screen below the packer assembly and travels out of the well screen into the filter pack (water injection through the well-screen packer assembly helps to settle the filter pack, as well as ensure that the filter pack completely surrounds the well screen in the annular space between the well screen and the temporary casing);

d. Slowly withdrawing the tremie pipes and well-screen packer assembly up the screened portion of the well so that the artificial filter pack is placed along the length of the screened portion; and

e. Simultaneously withdrawing the temporary casing surrounding the well screen and filter pack by pulling, rocking and/or vibrating the casing.

Placement of the engineered artificial titter pack around the screened portions of the slant well helps stabilize the subsea aquifer materials and prevent migration of fine sand and silt materials (from subsea aquifers) into the well. This both inhibits the screen portions from becoming clogged and results in a desalination feedwater water quality, as measured by turbidity and silt density indices (a measure of fouling in reverse osmosis desalination systems), that eliminates or minimizes the need for pre-treatment of the water prior to desalination.

In one embodiment, the well screens are centered inside the temporary casings through a system of centralizers or screen centering guides.

The present invention is also embodied in a method of minimizing variations in feedwater salinity, the method comprising providing a plurality of slant wells, each having a different angle below horizontal. Shallower-angled wells tend to produce water having greater salinity, whereas steeper-angled wells tend to produce water having lesser salinity. By varying the amounts of water pumped from shallower-angled wells versus steeper-angled wells, variations in feedwater salinity that occur due to natural variations in the hydrologic cycle can be minimized. Natural variations in the hydrologic cycle (such as wet and dry hydrologic periods) can impact the location of the freshwater-saltwater interface due to variations in fresh water flowing from the land to the ocean, sea, or inland lake.

On one embodiment, multiple well screens are placed in a single slant well to minimize variations in feedwater salinity in that well that occur due to natural variations in the hydrologic cycle. The slant well can be equipped with a submersible pumping system fitted with a dual-packer shroud assembly. Using the dual-packer shroud assembly, the slant well can selectively pump from upper or lower portions of the subsea aquifer, thereby varying feedwater salinity as required to help minimize variations in feedwater salinity due to hydrologic cycles. The dual-packer shroud assembly (DPSA) allows selective production from well screens both above and below the packers (maximum production), well screens above the upper packer only (lower salinity), well screens below the lower packer only salinity), or well screens between the packers (focused salinity).

Embodiments of the present invention include a telescoping slant well feedwater supply system for supplying water from an aquifer. The system comprises a primary well screen for admitting water from the aquifer (the primary well screen oriented along an axis angled below horizontal and having a substantially uniform cross-sectional area); a filter pack substantially surrounding the primary well screen; a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and a submersible pump contained within the pump house casing for pumping water admitted through the primary well screen. The cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

In another embodiment, the axis is straight. The system may further comprise a secondary well screen for admitting water from the aquifer, the secondary well screen oriented along the same axis but having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen. The system may additionally comprise a dual-valve assembly contained within the pump house casing. The dual-valve assembly may comprise a first valve for regulating the flow of water from the primary well screen to the submersible pump, and a second valve for regulating the flow of water from the secondary well screen to the submersible pump. In one embodiment, the first valve is a first pneumatic packer, and the second valve is a second pneumatic packer. The system may further comprise a first air line configured to extend from an air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer, and a second air line configured to extend from an air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer. The system may additionally comprise a tertiary well screen for admitting water from the aquifer, the tertiary well screen oriented along the axis between the first valve and the second valve. The dual-valve assembly may further comprise a shroud substantially surrounding the submersible pump. The shroud may have a plurality of holes through which water from the primary or secondary well screens can flow to the submersible pump. The dual-valve assembly may further comprise centering guides attached to the shroud for centering the submersible pump within the shroud.

Embodiments of the present invention also include a method of constructing a slant well feedwater supply system for supplying water from an aquifer. The method comprises the steps of placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings; placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings; and placing a filter pack in the space between the well screen and the one or more temporary casings.

In one embodiment, the method further comprises the step of withdrawing the one or more temporary casings. The step of placing the well screen may comprise the step of centering the well screen within the one or more temporary casings using centering guides. In the step of placing a telescoping plurality of casings, the telescoping plurality of casings may comprise a pump house casing. In one embodiment, the pump house casing has an upward end and a downward end, and the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing along the axis. The method may further comprise the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

In another embodiment, the step of placing the filter pack comprises the steps of extending one or more tremie pipes to the space between the well screen and the one or more temporary casings, and pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings. The step of extending the one or more tremie pipes may comprise the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides. In one embodiment, the one or more tremie pipes consist of three tremie pipes, and the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen. The step of placing the filter pack may further comprise the steps of placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer, and pumping water through the water pipe to settle the filter pack material. The method may further comprise the step of withdrawing the packer assembly and the one or more tremie pipes. The steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes lay be gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

Embodiments of the present invention also include a method for reducing salinity variation in feedwater supplied from a slant well system comprising an upper well screen and a lower well screen for admitting water from an aquifer, a submersible pump for pumping water admitted through the upper or lower well screens, an upper valve for regulating water flow from the upper well screen to the submersible pump, and a lower valve for regulating water flow from the lower well screen to the submersible pump. The method comprises the steps of controlling the upper valve to inhibit water flow from the upper well screen to the submersible pump if the salinity of the feedwater decreases below a first predetermined threshold, and controlling the lower valve to inhibit water flow from the lower well screen to the submersible pump if the salinity of the feedwater increases above a second predetermined threshold. In one embodiment, the upper valve, in the step of controlling the upper valve, is a first pneumatic packer, and the lower valve, in the step of controlling the lower valve, is a second pneumatic packer.

Other features of the invention should become more apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present invention will now be described, by way of example only, with reference to the following drawings.

FIG. **1** is an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to an inland desalination plant, in accordance with an embodiment of the present invention.

FIG. **2** is a side elevation view of a telescoped slant well having upper and lower well screens and showing water infiltration from the ocean and the freshwater-saltwater interface, in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casing cut away to show a submersible pump inside the pump house casing.

FIG. **3** is a side elevation view of a telescoped slant well having a single well screen interval and showing primary and secondary sources of water recharge to the slant well, in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screen shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing.

FIG. **4** is a side elevation view of a telescoped slant well having multiple screened intervals, in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing fitted with a dual-packer shroud assembly having both packers deflated for maximum well production.

FIGS. **5**A-**5**D are top plan views of four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration, a two-well array, a three-well array, and a four-well array, in accordance with embodiments of the present invention.

FIGS. **6**A and **6**B are top plan views of two slant well configurations, each having separate well head areas for the slant wells in the configuration, in accordance with embodiments of the present invention.

FIG. **7** is a side elevation view showing two telescoped slant wells extending from a common well head but at different angles below horizontal to produce water having different salinities (higher salinity production from the shallower-angle slant well and lower salinity production from the steeper-angle slant well), in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casings cut away to show submersible pumps inside the pump house casing.

FIG. **8** is a side elevation view of a telescoped slant well having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention.

FIG. **9** is a side elevation view of a telescoped slant well showing the placement of a single screened section centered within a temporary casing using centering guides and surrounded by an artificial filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

FIG. **10** is a side elevation view of a telescoped slant well illustrating the removal of the 20-inch diameter temporary casing surrounding the well screen and filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

FIG. **11** is a side elevation view of a telescoped slant well having a single screened section with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the filter pack cut away to show the well screen.

FIG. **12** is a side elevation view of a telescoped slant well having dual screened intervals with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the centering guides and filter pack cut away to show the well screen.

FIG. **13**A is a side elevation view of a telescoped slant well showing the placement of an artificial filter pack through a system of multiple tremie pipes in the annular space between the lower well screen and the temporary casing, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the tremie pipies and upper and lower well screens. FIG. **13**B is a cross-section view of the telescoped slant well of FIG. **13** A, taken along the line **13**-**13** in FIG. **13**A, showing the temporary casing, upper well screen, filter pack, tremie pipes, and tremie pipe guides.

FIG. **14**A is a side elevation view of a telescoped slant well showing the placement and settlement of an engineered artificial filter pack through a multi-step process of placing the filter pack by pumping filter pack material through tremie pipes under pressure, simultaneously removing the temporary casing surrounding the tremie pipes, settling the filter pack using an in-screen packer assembly, and gradually withdrawing the in-screen packer assembly, in accordance with an embodiment of the present invention, with the casings and well screens cut away to show the in-screen packer assembly. FIG. **14**B is a detail view of the telescoped slant well of FIG. **14**A, showing the filter pack placement.

FIG. **15** is a chart of sieve opening versus percent of filter material passing the well screen slots for designing an engineered filter pack from site-specific samples of aquifer materials.

FIG. **16** is a side elevation view of a multiple-screened, telescoped slant well showing how the slant well can pump water with higher or lower salinity because of variations in the freshwater-saltwater interface due to natural variations in the hydrologic cycle, in accordance with an embodiment of the present invention, with the pump house easing cut away to show a submersible pump inside the pump house casing.

FIG. **17** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the lowermost screen only (upper packer inflated, lower packer deflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **18** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the uppermost screen only (upper packer deflated, lower packer inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **19** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the well screen portion between the dual packers (upper and lower packers inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **20** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for maximum production (both upper and lower packers deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **21** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from below the lower packer (upper packer inflated and lower packer deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **22** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from above the upper packer (upper packer deflated and lower packer inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **23** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from between the dual packers (both upper and lower packers inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is generally embodied in a slant well or system of slant wells that produces water from permeable deposits near or beneath saline water bodies (e.g., oceans, seas, or inland lakes). The invention can provide a long-term, sustainable feedwater supply for a desalination plant with virtually unlimited recharge potential.

With reference now to the illustrative drawings, and particularly to FIG. **1**, there is shown an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to a desalination plant, in accordance with an embodiment of the present invention. Permeable materials comprising the subsea aquifer **1** are recharged from the overlying ocean **2**. The slant well **3** receives recharge from induced infiltration of ocean water **4** and pumps this feedwater to a desalination plant **5** through a pipeline **6**. The desalination plant **5** pumps out freshwater through a freshwater pipeline **7** to meet inland water supply demands.

With reference now to FIG. **2**, there is shown a telescoped slant well **8** configured for use in a feedwater supply system **17**, in accordance with an embodiment of the present invention. In one embodiment, the slant well is drilled at a low angle below horizontal using a dual rotary drilling rig or other suitable device to a total lineal length of approximately 1,000 feet or more. In one particular embodiment, the slant well is drilled at an angle of approximately 23 degrees below horizontal. The telescoped slant well has an upper well screen **9** and a lower well screen **10** for admitting water from a saltwater aquifer **14**. A submersible pump **11** pumps water out of the slant well to a desalination plant. The slant well is recharged from induced infiltration of water **13** that flows from the ocean floor **12** and lateral offshore sources through the saltwater aquifer **14**. The saltwater aquifer meets the freshwater aquifer beneath the land surface at a freshwater-saltwater interface **15**. Saline water is pumped from the slant well **8** to the desalination plant via an underground pipeline **16** connected to the buried slant well head. In one embodiment, the buried slant well head is connected to the pipeline **16** via a caisson (not shown) sunk into the land surface.

The slant well **8** is part of a feedwater supply system **17** that comprises the slant well and the pipeline **16**. Because the slant well is buried beneath the land surface and ocean floor, the feedwater supply system avoids entrainment and impingement impacts to marine life. Additionally, the filtration process performed by the subsurface aquifer **14** reduces or eliminates costly reverse osmosis pretreatment that would otherwise need to be performed at a desalination plant. Furthermore, because the slant well is completed eland and ocean surface, aesthetic impacts are minimized or eliminated.

Various configurations of a slant well for use in a feedwater supply system will now be described in more detail. With reference to FIG. **3**, there is shown a telescoped slant well **18** having an artificial filter pack **19** and a single well screen interval **20** in accordance with an embodiment of the present invention. The slant well extends through the freshwater-saltwater interface **21**. A primary recharge flow **22** and secondary recharge flow **23** provide recharge to the slant well. Sustained recharge to the slant well is largely provided by induced recharge from the ocean through the primary recharge flow **22** due to the hydraulic head difference between the ocean level **24** and the slant well pumping level **25**. The location of the freshwater-saltwater interface **21** is governed by the height of the freshwater elevation **26**.

A slant well in accordance with the present invention can have multiple screened intervals for providing greater flexibility in feedwater production. With reference to FIG. **4**, there is shown a telescoped slant well **27** having an artificial filter pack **28**, multiple screened intervals **29** (upper and lower), and a submersible pump **30** fitted with a dual-packer shroud assembly, in accordance with an embodiment of the present invention. In the configuration shown in FIG. **4**, both of the dual packers are deflated so that water is drawn into the well through both the upper and lower screened intervals. This configuration is for maximum feedwater production. In other configurations, one or both of the dual packers can be inflated so that water is drawn into the well through less than the full length of the screened intervals. These other configurations are described in greater detail below with respect to FIGS. **17-23**.

A feedwater supply system in accordance with the present invention can comprise a plurality of slant wells. With reference to FIGS. **5**A-**5**D, there are shown four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration **31**, a two-well array **32**, a three-well array **33**, and a four-well array **34**, in accordance with embodiments of the present invention. In each configuration, the slant wells all begin in the same vicinity of each other, i.e., they have common well head area **35**. As shown in FIGS. **5**A-**5**D, the well head area is located above the high tide line to maximize the undersea screened portion **36** of the slant wells.

With reference now to FIGS. **6**A and **6**B, there are shown a parallel slant well configuration **37** and a nonparallel slant well configuration **38**, in accordance with embodiments of the present invention. Each of these slant well configurations has a separate well head area for the slant wells in the configuration.

With reference now to FIG. **7**, there are shown a shallower-angle slant well **39** and a steeper-angle slant well **40**, the slant wells extending from a common wellhead area **41** but at different angles α_1 and α_2 below horizontal to produce water having different salinities, in accordance with an embodiment of the present invention. The freshwater-saltwater interface **44** is also shown to illustrate higher salinity production from the shallower-angle slant well **39** and lower salinity production from the steeper-angle slant well **40**.

Construction of a stank well for use in a feedwater supply system will now be described in more detail. In one embodiment, the initial construction of the slant well involves placing a telescoping plurality of casings beneath the land surface and ocean floor. With reference to FIG. **8**, there is shown an initial step in the construction of a telescoped slant well **45** having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention. The slant well comprises a 26-inch permanent casing **46** for the sanitary seal, a 24-inch permanent pump house casing **47**, a 22-inch temporary casing **48**, and a 20-inch temporary casing **49**.

With reference now to FIG. **9**, there is shown a second step in the construction of a telescoped slant well **50** having a single 12-inch-diameter well screen section **51**, in accordance with an embodiment of the present invention. An artificial filter pack **52** has been placed around the well screen section. The well screen section has been centered within a 20-inch temporary casing **54** using centering guides **53**.

Before operating a slant well in accordance with the present invention, the temporary casings surrounding the artificial filter pack and well screen section need to be withdrawn. FIGS. **10** and **11** illustrate the process of removing a 20-inch and 22-inch temporary casings from a telescoped slant well having a single well screen section. FIG. **10** shows a telescoped slant well **55** having a single well screen section **56** surrounded by an artificial filter pack **57** and centered using centering guides **58**. Dashed line **59** shows the extent of the 20-inch temporary casing prior to the start of the removal process. FIG. **11** shows a telescoped slant well **60** having a single well screen section **61** with both the 20-inch and 22-inch temporary casings removed. The top of the well screen **62** is cut off within the 24-inch pump house casing **63**, which is fitted with a seal **64** at the bottom of the pump house casing.

With reference now to FIG. **12**, there is shown a telescoped slant well **65** having dual screened intervals **66** and the temporary casings removed, in accordance with an embodiment of the present invention. Dashed line **67** shows the extent of the 20-inch temporary casing prior to the start of the removal process. The top of the well screen **68** is cut off within the 24-inch pump house casing, which is fitted with a seal **69** at the bottom of the pump house casing.

Before completing construction of a slant well in accordance with the present invention, the artificial filter pack needs to be placed and settled around the well screen sections. With reference to FIGS. **13**A and **13**B, there is shown a telescoped slant well **70** with an artificial filter pack **71** being placed through a system of multiple tremie pipes **72** in the annular space between the lower well screen **73** and the temporary casing **74**, in accordance with an embodiment of the present invention. The tremie pipes **72** are positioned using tremie pipe guides **75**, **76**, **77** and **78**.

FIGS. **14**A and **14**B further illustrate the process of placing and settling the artificial filter pack. These figures show a telescoped slant well **79** with an artificial filter pack **80** being placed and settled through a multi-step process. The filter pack is placed by pumping filter pack material **81** through the multiple tremie pipes **82** under pressure. Simultaneously, the temporary casing **83** surrounding the tremie pipes is removed and the filter pack **80** is settled using an in-screen packer assembly **84**. The in-screen packer assembly is configured to be slid inside a well screen. A water pipe extends from a water pump (not shown) through a hole in the in-screen packer. The water pump may be a standard water pump known to persons of ordinary skill in the art, with sufficient flow and pressure to cause water at the depth below the packer to flow outward through the well screen portion below the packer, thereby settling the filter pack in the vicinity of the packer. The in-screen packer assembly and tremie pipes are gradually withdrawn so that the artificial filter pack is placed and settled along the entire length of the well-screen portion of the slant well.

An engineered filter pack is designed to stabilize the subsea aquifer materials and, after proper development, prevent migration of fine sand and silt materials from the subsea aquifer into the well. With reference to FIG. **15**, there is shown an example chart of sieve opening versus percent of titter material passing the well screen slots for designing an engineered filter pack (line **85**) from site-specific samples of aquifer materials (line **86**) using the Terzaghi Migration Factor **87** as well as the filter pack sorting factor **88** and percentage of filter material passing the well screen slots **89**. This figure illustrates the principles behind the design of the artificial filter pack. A key purpose of the filter pack is to stabilize the aquifer. A key purpose of the well screen is to stabilize the filter pack.

To design the engineered filter pack, site-specific samples of aquifer materials are taken. It is next determined what sieve opening would pass 85 percent of the aquifer materials in the finest zone. In the example shown in FIG. **15**, it is determined that a sieve opening of approximately 0.6 millimeters would pass 85 percent of the finest aquifer materials within the screened interval of the well. The grain sizes of the filter pack are then chosen such that the 15-percent-passing filter pack

pump intake **147** from the screened section **148** between the packers. Water entering through the upper or lower well screens is prevented from entering the pump intake by means of the inflated upper packer **145** and lower packer **146**.

A slant well feedwater supply system in accordance with the present invention can be constructed near and/or beneath any saline water source, but more preferably is constructed where a river delta deposit meets the ocean, where a major drainage (such as a creek, stream or river) discharges into the ocean, or where an aquifer system under a land surface extends offshore. An initial field investigation is preferably conducted to determine the potential of a site to yield water for a desalination plant. This exploratory work may involve drilling boreholes and test wells to an appropriate depth both onshore and offshore to properly characterize the subsurface aquifer system, which may typically be sand and gravels but may also include secondary porosity features in consolidated rock aquifers (e.g. carbonate aquifers). In one embodiment, the boreholes and test wells are drilled 50 to 200 feet deep. The lithologic characterization of the aquifers may also indicate the quality of the water that might be supplied for a well drilled at that site (e.g., in terms of total dissolved solids (TDS), chlorides and other chemical constituents of concern in a desalination feedwater supply and how those constituents vary with depth).

In one embodiment, the slant well feedwater supply system extends at approximately a 23-degree angle below horizontal to a total length of approximately 350 feet and is capable of providing 2,000-gpm feedwater supply having an average silt density index of approximately 0.58 and an NTU between approximately 0.15 and 0.33. Of the total length, the first approximately 130 feet can comprise a blank casing, followed by approximately 220 feet of a well screen. The well screen can comprise a plurality of Roscoe Moss Full-Flo louver well screens having 3/32-inch slots, the plurality welded together end-to-end to form the complete well screen. The well screen and blank casing can have an inner diameter of 12⅛ inches and a wall thickness of 5/16-inches. In one embodiment, the well screen and blank casing comprise 316L stainless steel. The artificial filter pack can comprise Colorado Silica ¼×16 packed approximately 5 inches thick around the well screen. In one particular embodiment, the full scale system comprises a plurality of seven 1,000-foot slant wells, with each well supplying a feedwater supply of approximately 3,000 gpm for a total supply of approximately 30 mgd.

The foregoing detailed description of the present invention is provided for purposes of illustration, and it is not intended to be exhaustive or to limit the invention to the particular embodiments disclosed. The embodiments may provide different capabilities and benefits, depending on the configuration used to implement the key features of the invention. Accordingly, the scope of the invention is defined only by the following claims.

What is claimed is:

1. A telescoping slant well feedwater supply system for supplying water from a subsurface aquifer system, the feedwater supply system comprising:

a primary well screen for initially admitting water from the aquifer system, the primary well screen oriented along an axis angled less than ninety degrees below horizontal and having a substantially uniform cross-sectional area;

a filter pack substantially surrounding and adjacent to the primary well screen;

a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and

a submersible pump contained within the pump house casing for pumping water admitted through the primary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

2. The system of claim **1**, wherein the axis is straight.

3. The system of claim **1**, further comprising a secondary well screen for admitting water from the aquifer system, the secondary well screen oriented along the axis and having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen.

4. The system of claim **3**, further comprising a dual-packer assembly contained within the pump house casing, the dual-packer assembly comprising:

a first packer for regulating the flow of water from the primary well screen to the submersible pump; and

a second packer for regulating the flow of water from the secondary well screen to the submersible pump.

5. The system of claim **4**, wherein:

the first packer is a first pneumatic packer; and

the second packer is a second pneumatic packer.

6. The system of claim **5**, further comprising:

a first air line configured to extend from an air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer; and

a second air line configured to extend from an air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer.

7. The system of claim **4**, further comprising a tertiary well screen for admitting water from the aquifer system, the tertiary well screen oriented along the axis between the first packer and the second packer.

8. The system of claim **4**, wherein:

the dual-packer assembly further comprises a shroud substantially surrounding the submersible pump; and

the shroud has a plurality of holes through which water from the primary or secondary well screens can flow to the submersible pump.

9. The system of claim **8**, wherein the dual-packer assembly further comprises centering guides attached to the shroud for centering the submersible pump within the shroud.

10. A method of constructing a slant well feedwater supply system for supplying water from an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings;

placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings, the well screen comprising a first portion having a substantially uniform cross-sectional area and a second portion having a substantially uniform cross-sectional area greater than the cross-sectional area of the first portion; and

placing a filter pack in the space between the well screen and the one or more temporary casings.

11. The method of claim **10**, further comprising the step of withdrawing the one or more temporary casings.

12. The method of claim **10**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

13. The method of claim **10**, wherein, in the step of placing a telescoping plurality of casings, the telescoping plurality of casings further comprises a pump house casing.

14. The method of claim **13**, wherein:

the pump house casing has an upward end and a downward end; and

the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing along the axis.

15. The method of claim **14**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

16. The method of claim **10**, wherein the step of placing the filter pack comprises the steps of:

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings; and

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings.

17. The method of claim **16**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

18. The method of claim **17**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

19. The method of claim **16**, wherein the step of placing the filter pack further comprises the steps of:

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer; and

pumping water through the water pipe to settle the filter pack material.

20. The method of claim **19**, further comprising the step of withdrawing the packer assembly and the one or more tremie pipes.

21. The method of claim **20**, further comprising the step of withdrawing the one or more temporary casings;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

22. A method for reducing salinity variation in feedwater supplied from a slant well system comprising an upper well screen and a lower well screen for admitting water from an aquifer, a submersible pump for pumping water admitted through the upper or lower well screens, an upper packer for regulating water flow from the upper well screen to the submersible pump, and a lower packer for regulating water flow from the lower well screen to the submersible pump, the method comprising the steps of:

controlling the upper packer to inhibit water flow from the upper well screen to the submersible pump if the salinity of the feedwater decreases below a first predetermined threshold; and

controlling the lower packer to inhibit water flow from the lower well screen to the submersible pump if the salinity of the feedwater increases above a second predetermined threshold.

23. The system of claim **22**, wherein:

the upper packer, in the step of controlling the upper packer, is a first pneumatic packer; and

the lower packer, in the step of controlling the lower packer, is a second pneumatic packer.

24. A method of constructing a slant well feedwater supply system for supplying water from an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings and a pump house casing, the pump house casing having an upward end and a downward end;

placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings and so that the well screen extends upwardly through the downward end of the pump house casing along the axis; and

placing a filter pack in the space between the well screen and the one or more temporary casings.

25. The method of claim **24**, further comprising the step of withdrawing the one or more temporary casings.

26. The method of claim **24**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

27. The method of claim **24**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

28. The method of claim **24**, wherein the step of placing the filter pack comprises the steps of:

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings; and

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings.

29. The method of claim **28**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

30. The method of claim **29**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

31. The method of claim **28**, wherein the step of placing the filter pack further comprises the steps of:

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer; and

pumping water through the water pipe to settle the filter pack material.

32. The method of claim **31**, further comprising the step of withdrawing the packer assembly and the one or more tremie pipes.

33. The method of claim **32**, further comprising the step of withdrawing the one or more temporary casings;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

34. A method of constructing a slant well feedwater supply system for supplying water from an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings;

placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings;

placing a filter pack in the space between the well screen and the one or more temporary casings; and

withdrawing the one or more temporary casings;

wherein the step of placing the filter pack comprises the steps of

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings,

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings,

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer,

pumping water through the water pipe to settle the filter pack material, and

withdrawing the packer assembly and the one or more tremie pipes;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

35. The method of claim **34**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

36. The method of claim **34**, wherein, in the step of placing a telescoping plurality of casings, the telescoping plurality of casings further comprises a pump house casing.

37. The method of claim **36**, wherein:

the pump house casing has an upward end and a downward end; and

the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing along the axis.

38. The method of claim **37**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

39. The method of claim **34**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

40. The method of claim **39**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

41. A telescoping slant well feedwater supply system for supplying water from a subsurface aquifer system, the feedwater supply system comprising:

a primary well screen for admitting water from the aquifer system, the primary well screen oriented along an axis angled less than ninety degrees below horizontal and having a substantially uniform cross-sectional area;

a filter pack substantially surrounding and adjacent to the primary well screen;

a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area;

a submersible pump contained within the pump house casing for pumping water admitted through the primary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen; and

a dual-packer assembly contained within the pump house casing, the dual-packer assembly comprising:

a first packer for regulating the flow of water from the primary well screen to the submersible pump; and

a second packer for regulating the flow of water from the secondary well screen to the submersible pump.

42. The system of claim **41**, wherein:

the first packer is a first pneumatic packer; and

the second packer is a second pneumatic packer.

43. The system of claim **42**, further comprising:

a first air line configured to extend from an air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer; and

a second air line configured to extend from an air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer.

44. The system of claim **41**, further comprising a tertiary well screen for admitting water from the aquifer system, the tertiary well screen oriented along the axis between the first packer and the second packer.

45. The system of claim **41**, wherein:

the dual-packer assembly further comprises a shroud substantially surrounding the submersible pump; and

the shroud has a plurality of holes through which water from the primary or secondary well screens can flow to the submersible pump.

46. The system of claim **45**, wherein the dual-packer assembly further comprises centering guides attached to the shroud for centering the submersible pump within the shroud.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 8,056,629 B2
APPLICATION NO. : 12/748886
DATED : November 15, 2011
INVENTOR(S) : Dennis E. Williams

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

At column 2, line 47, “Placing” should be -- b. Placing --.

At column 2, line 65, “titter” should be -- filter --.

At column 3, line 38, after “only” insert -- (higher --.

At column 4, line 64, “lay” should be -- may --.

At column 7, line 6, “easing” should be -- casing --.

At column 8, line 46, “eland” should be -- below the land --.

At column 9, line 39, “stank” should be -- slant --.

At column 11, line 36, “flow” should be -- now --.

At column 11, line 47, “8” should be -- 18 --.

Signed and Sealed this
Tenth Day of July, 2012

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office

US 20120292012A1

(19) United States

(12) Patent Application Publication

Williams

(10) Pub. No.: US 2012/0292012 A1

(43) Pub. Date: Nov. 22, 2012

(54) **DESALINATION SUBSURFACE FEEDWATER SUPPLY AND BRINE DISPOSAL**

(75) Inventor: **Dennis E. Williams**, Altadena, CA (US)

(73) Assignee: **GEOSCIENCE Support Services, Inc.**, La Verne, CA (US)

(21) Appl. No.: **13/295,990**

(22) Filed: **Nov. 14, 2011**

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/748,886, filed on Mar. 29, 2010, now Pat. No. 8,056,629.

(60) Provisional application No. 61/293,134, filed on Jan. 7, 2010.

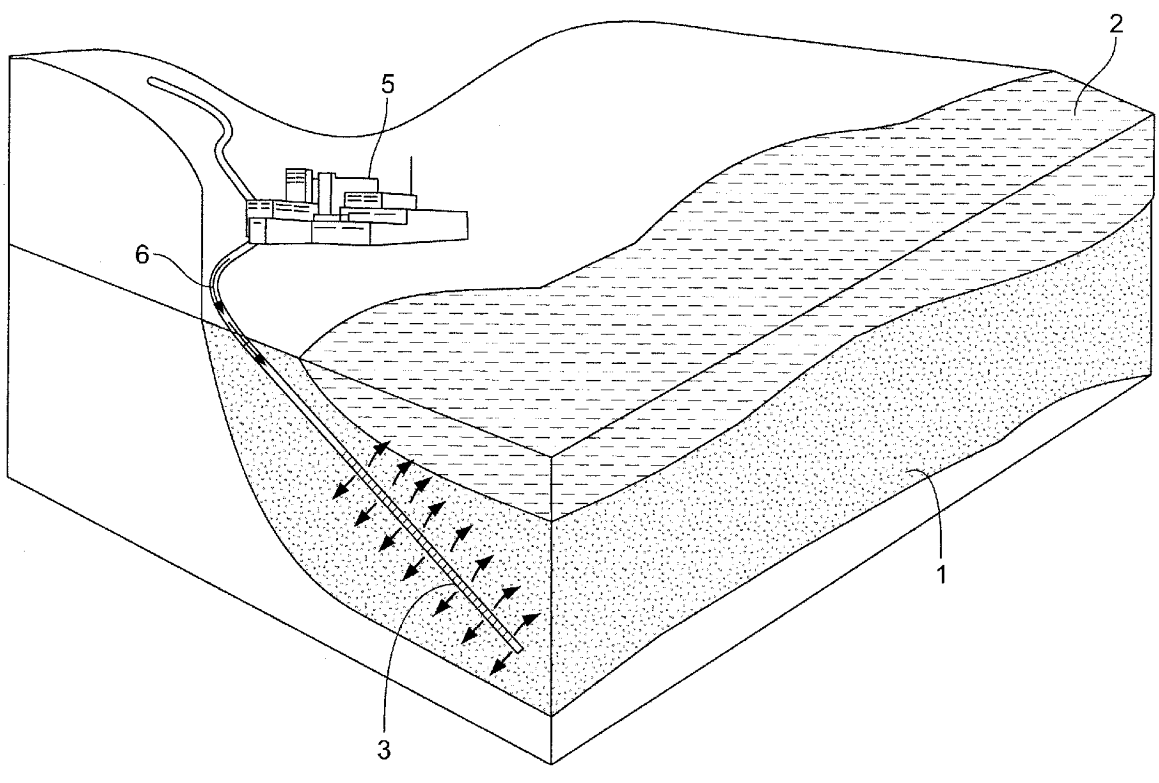
Publication Classification

(51) **Int. Cl.**
E21B 43/00 (2006.01)

(52) **U.S. Cl.** **166/105**

(57) **ABSTRACT**

A system is disclosed for supplying water to a desalination plant from a subsurface feedwater supply using one or more slant or horizontally directionally drilled ("HDD") wells, and for concentrate disposal (e.g., injection of brine). A method is disclosed for constructing a slant or HDD well feedwater supply system for supplying water from a subsurface feedwater supply or to inject concentrate into a subsea aquifer.



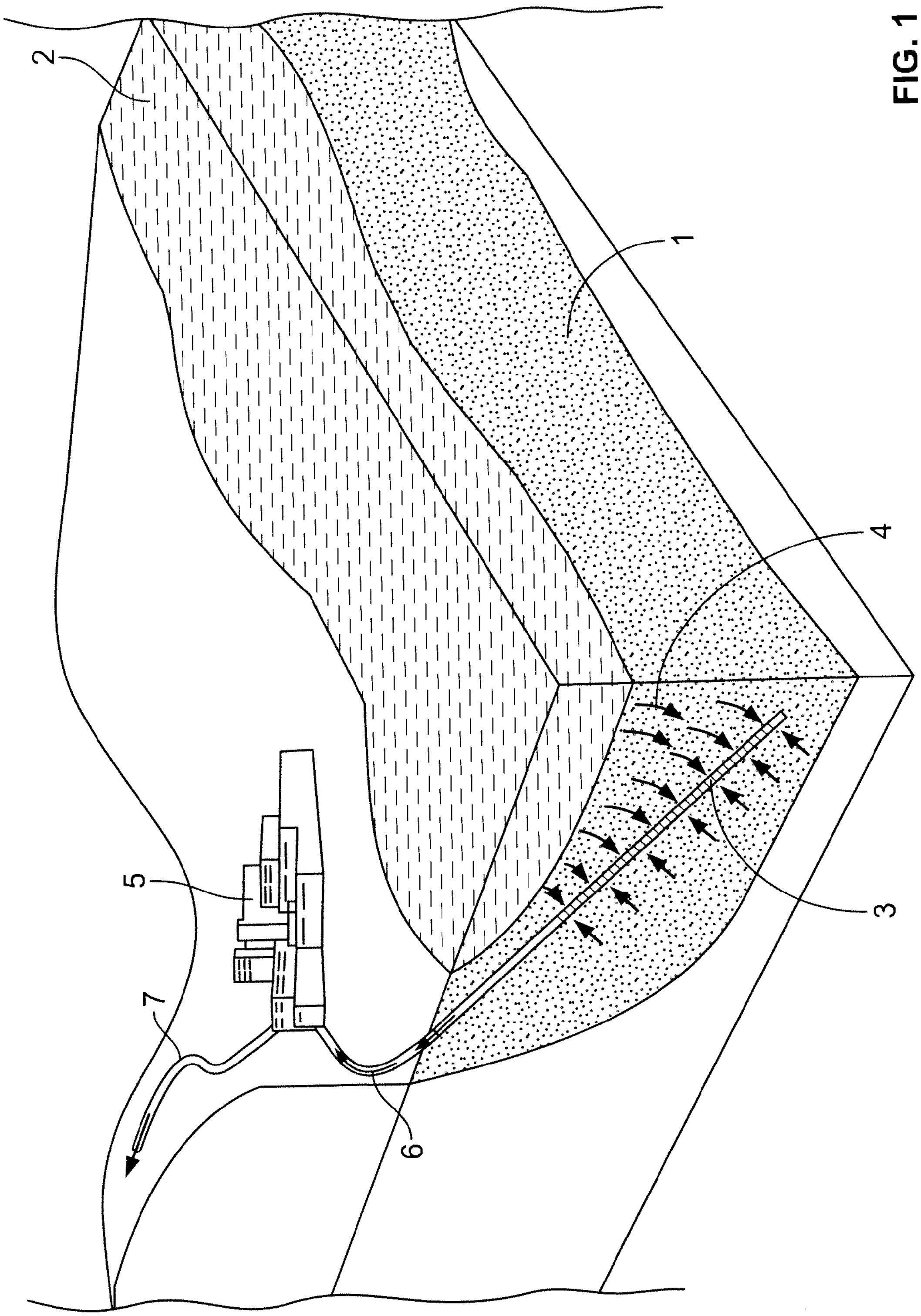


FIG. 1

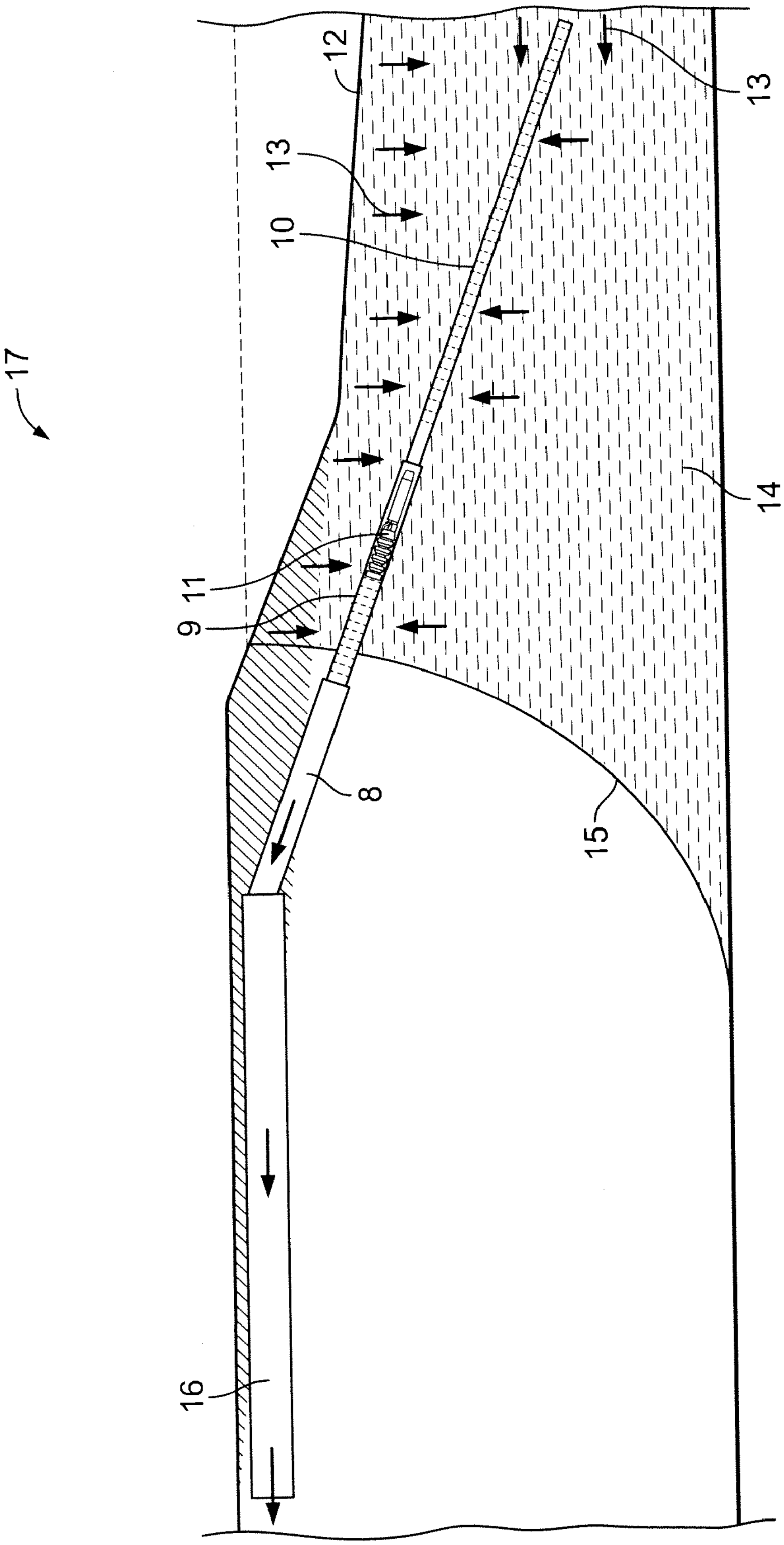


FIG. 2

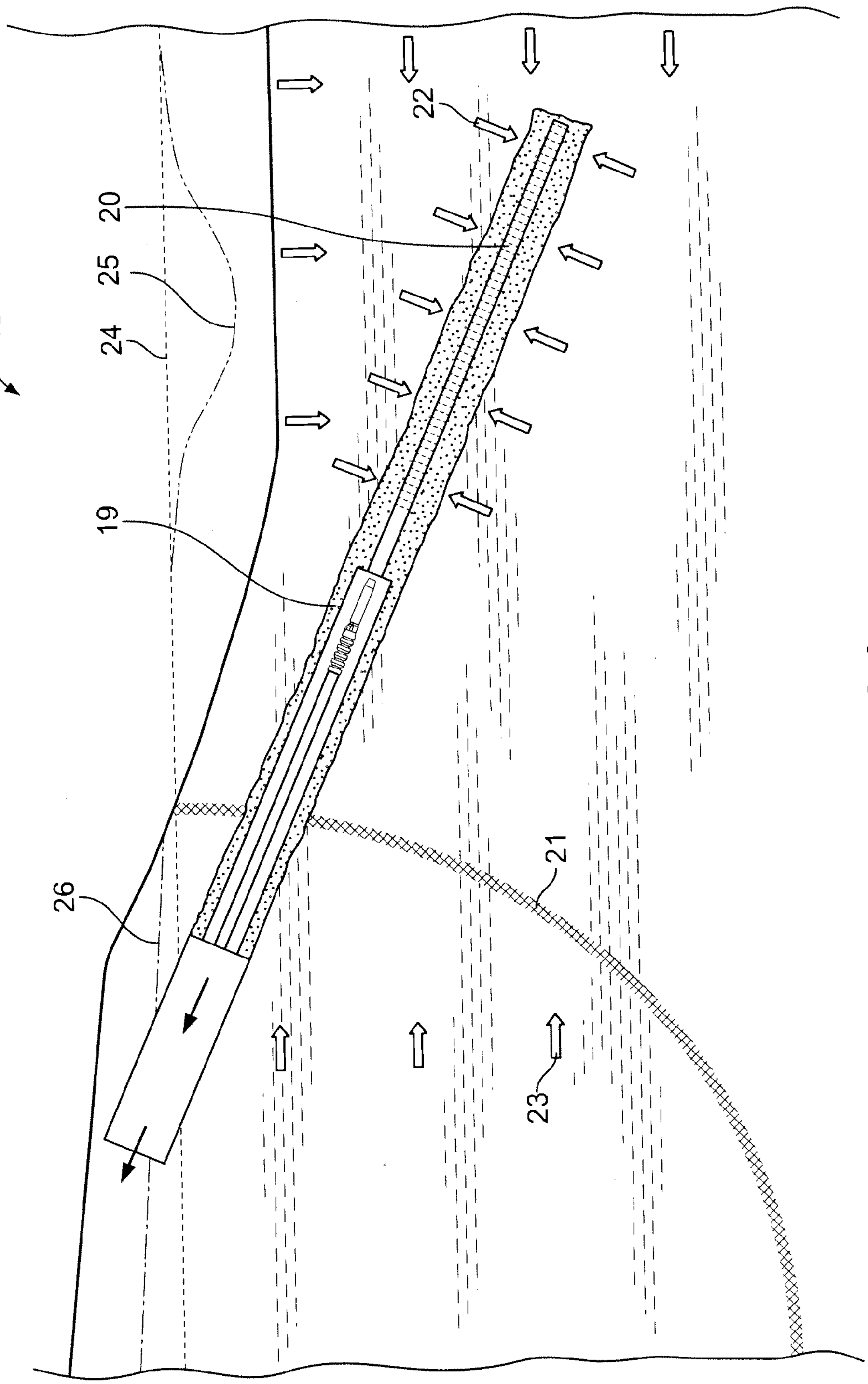


FIG. 3

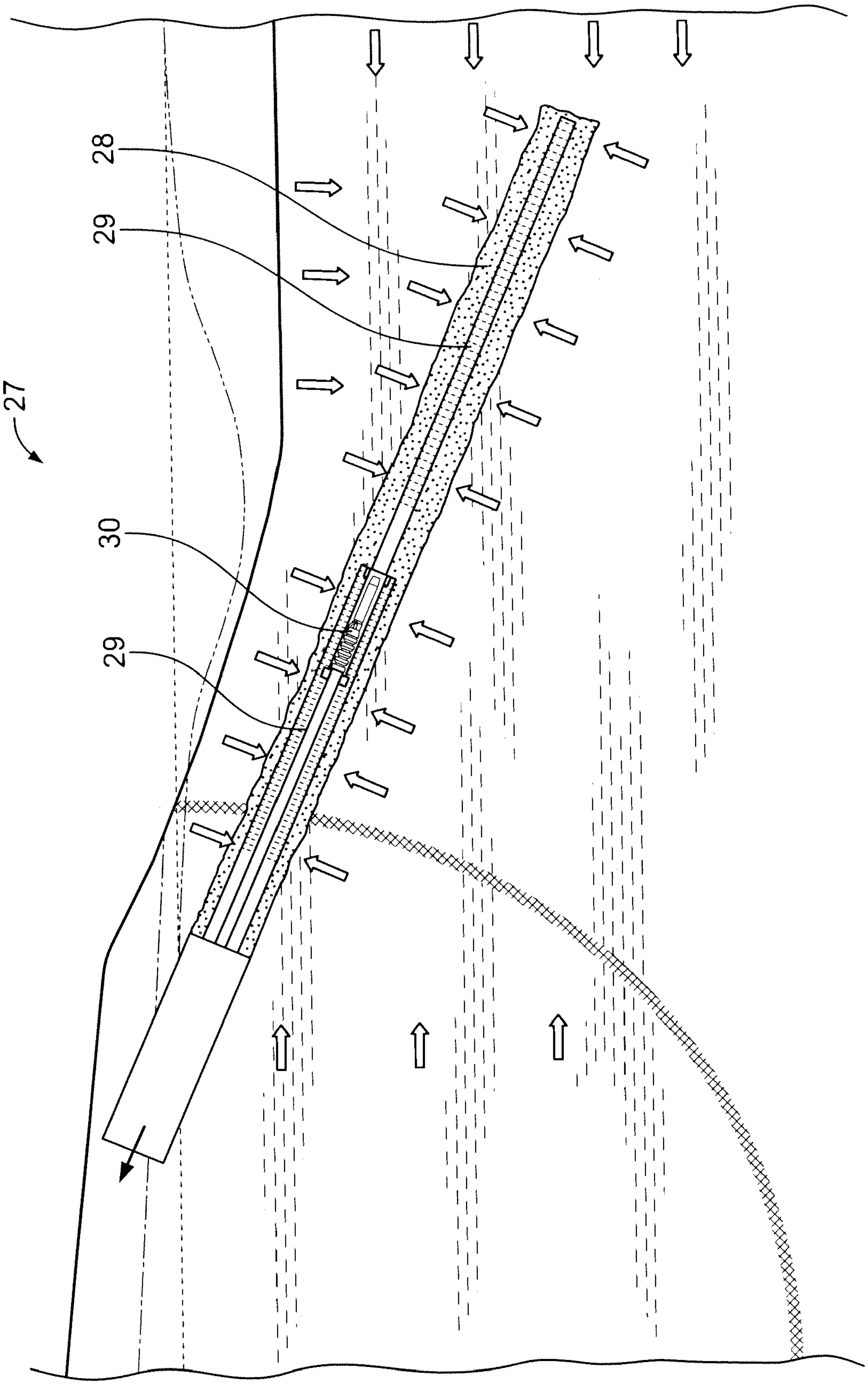


FIG. 4

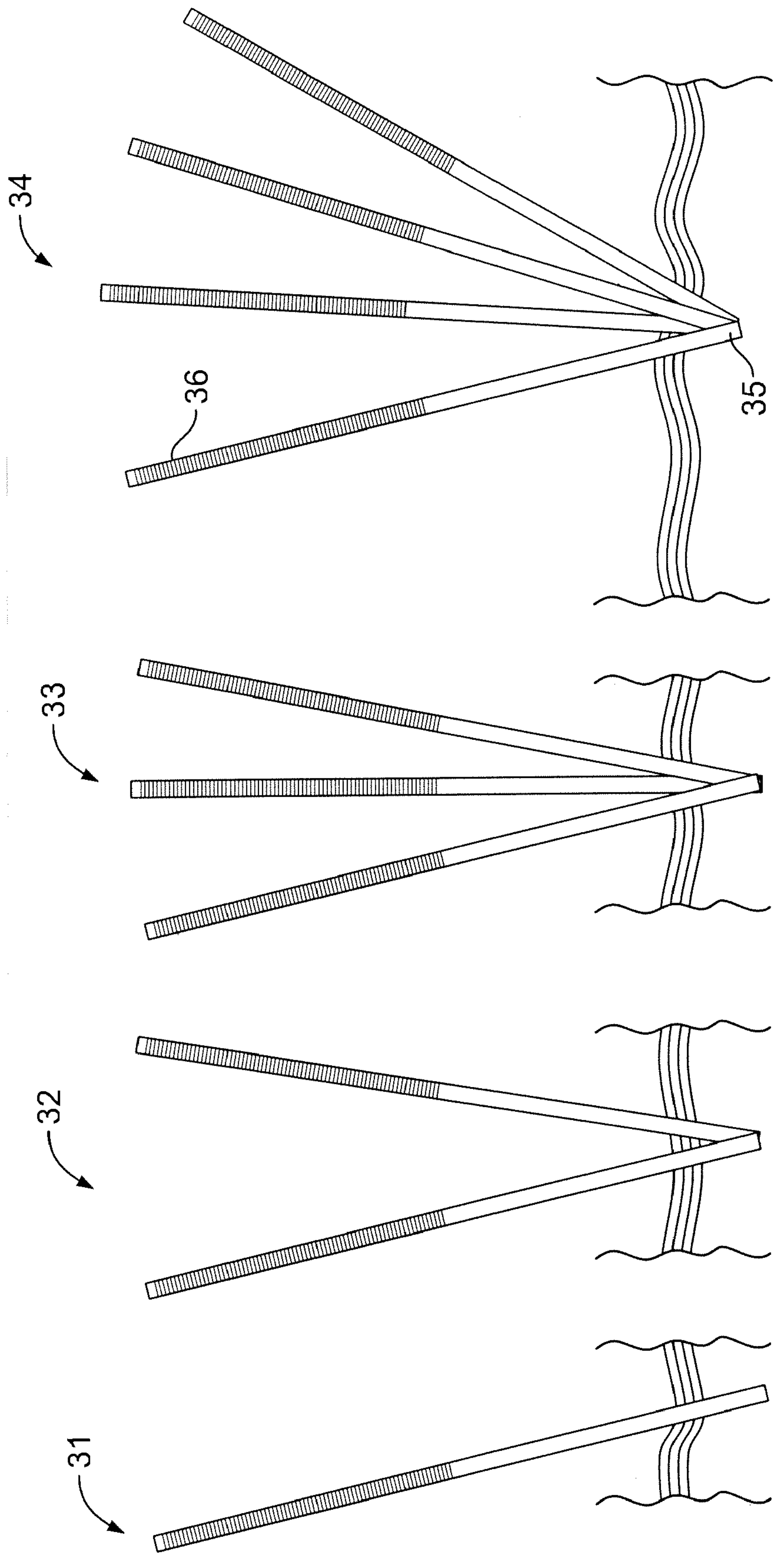


FIG. 5D

FIG. 5C

FIG. 5B

FIG. 5A

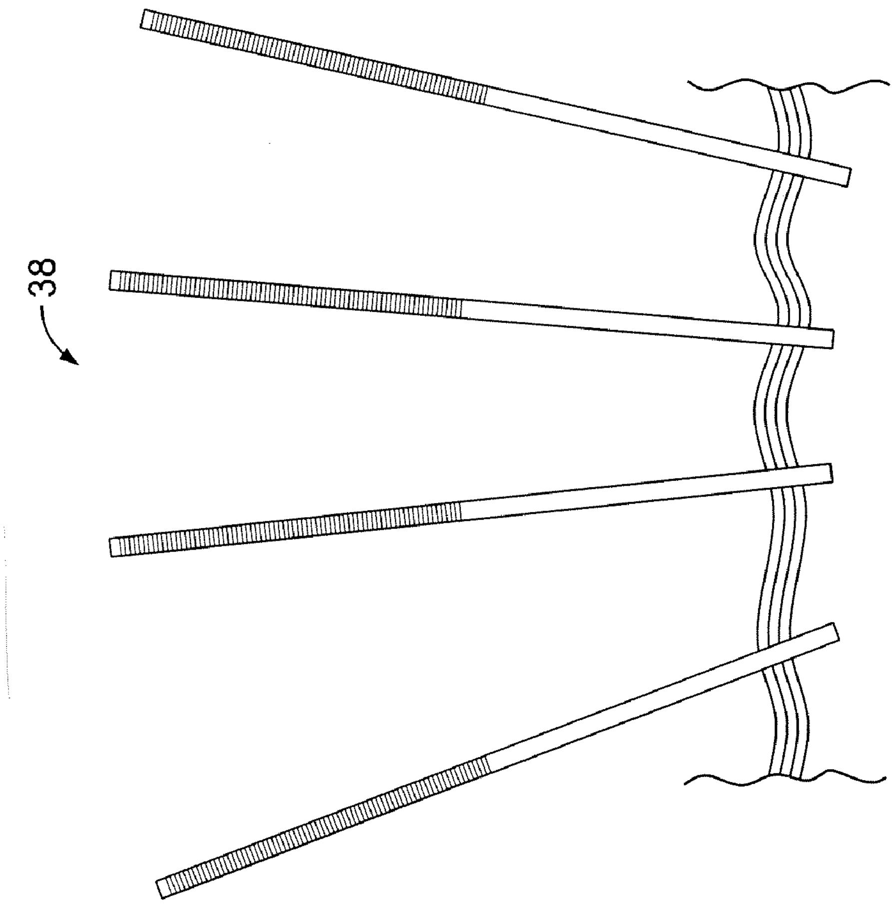


FIG. 6B

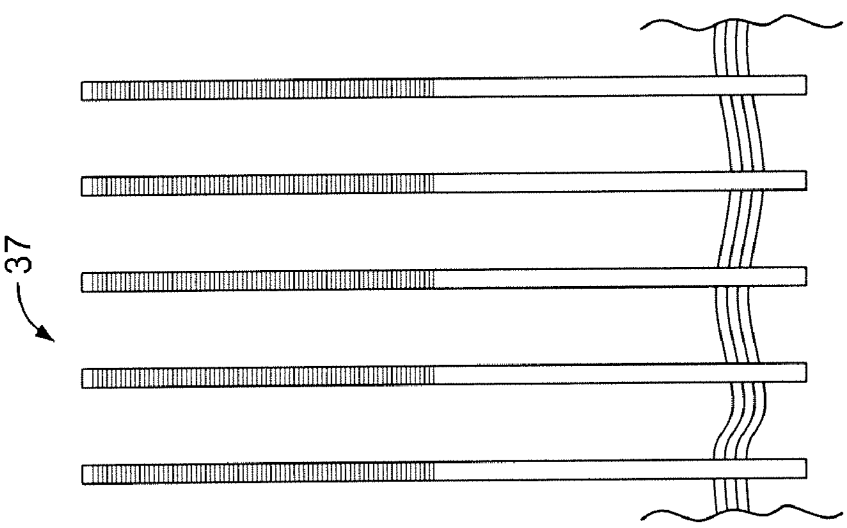


FIG. 6A

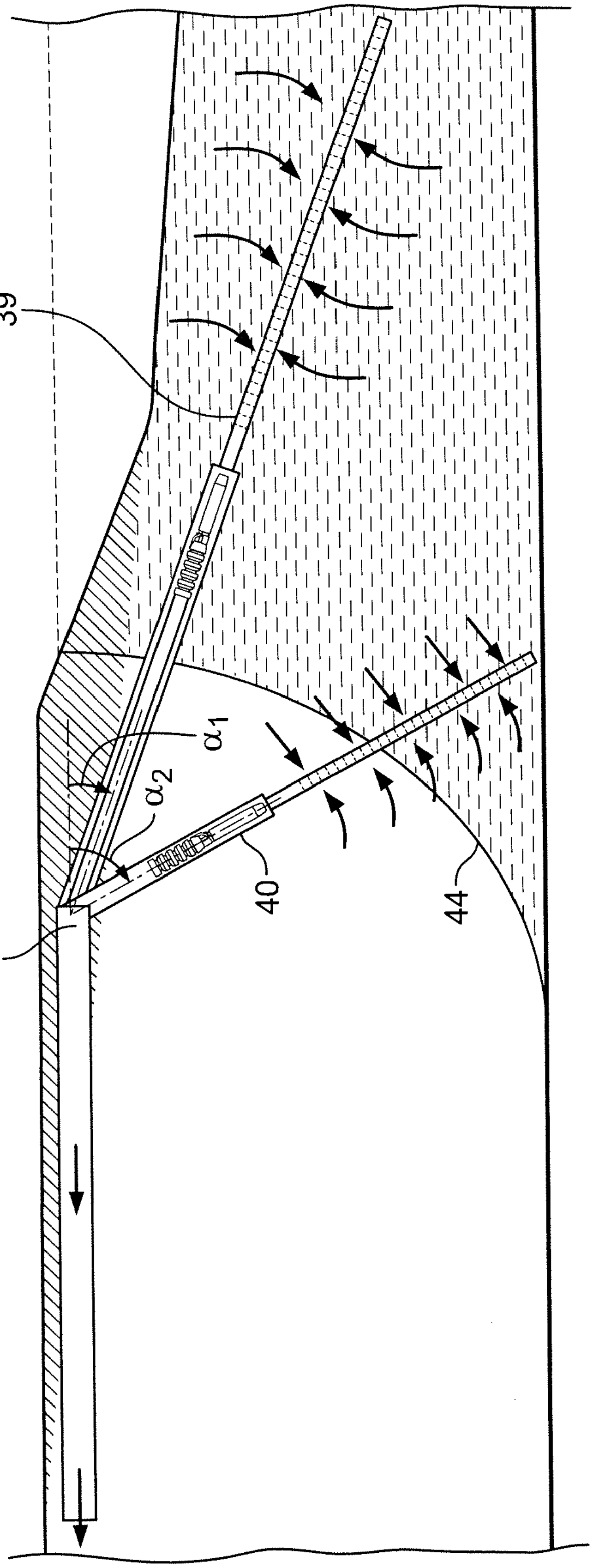


FIG. 7

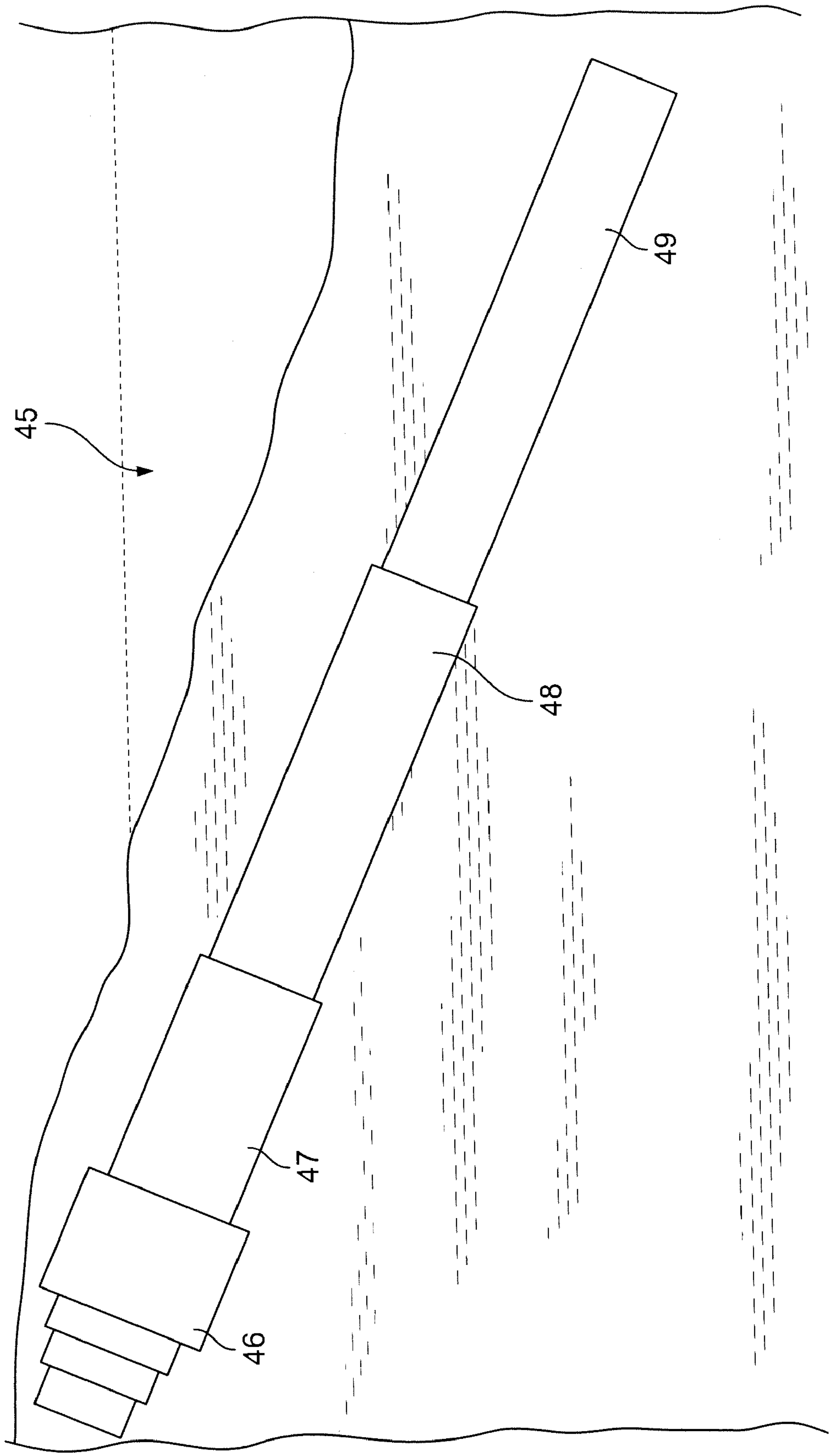


FIG. 8

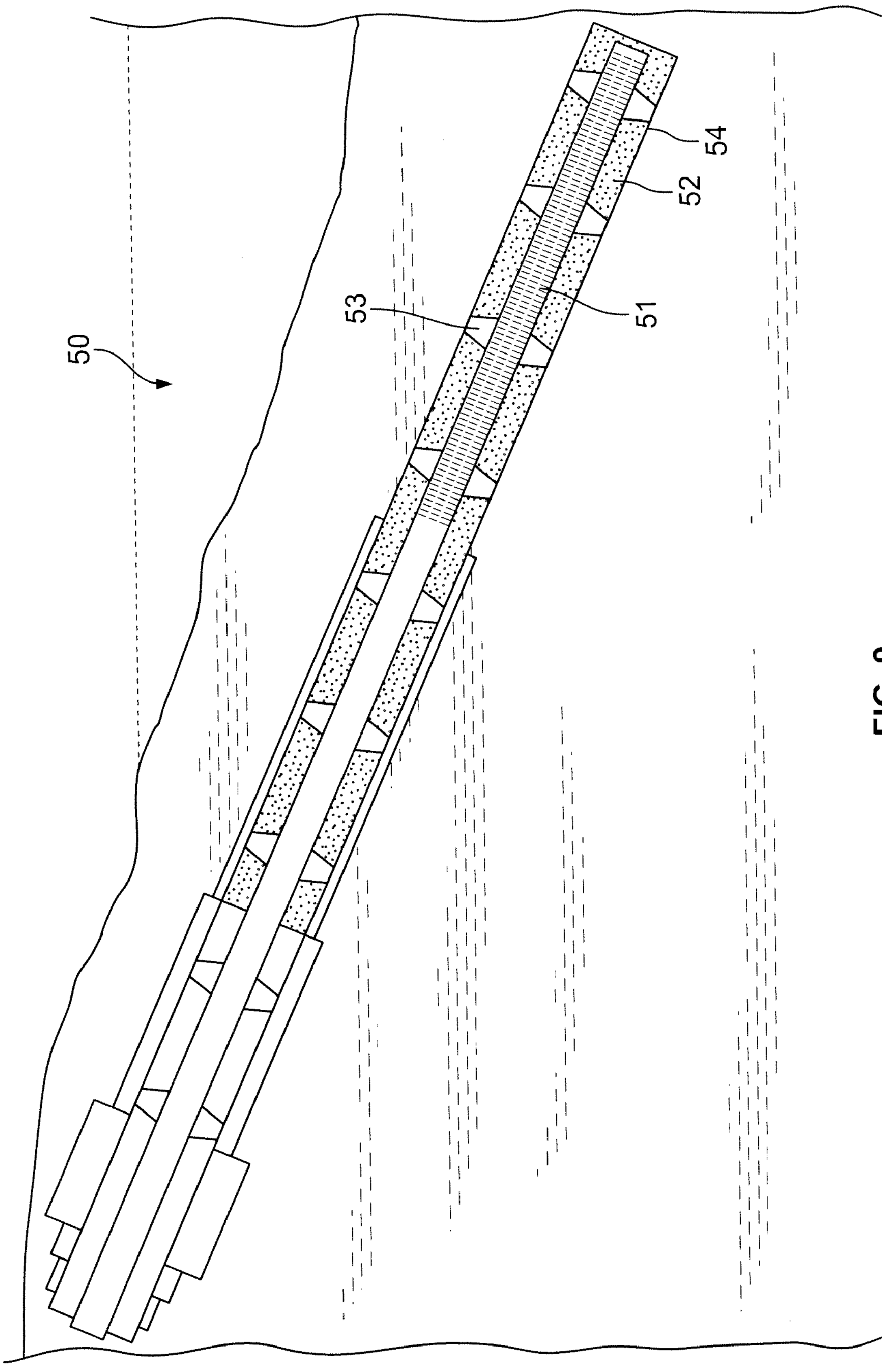


FIG. 9

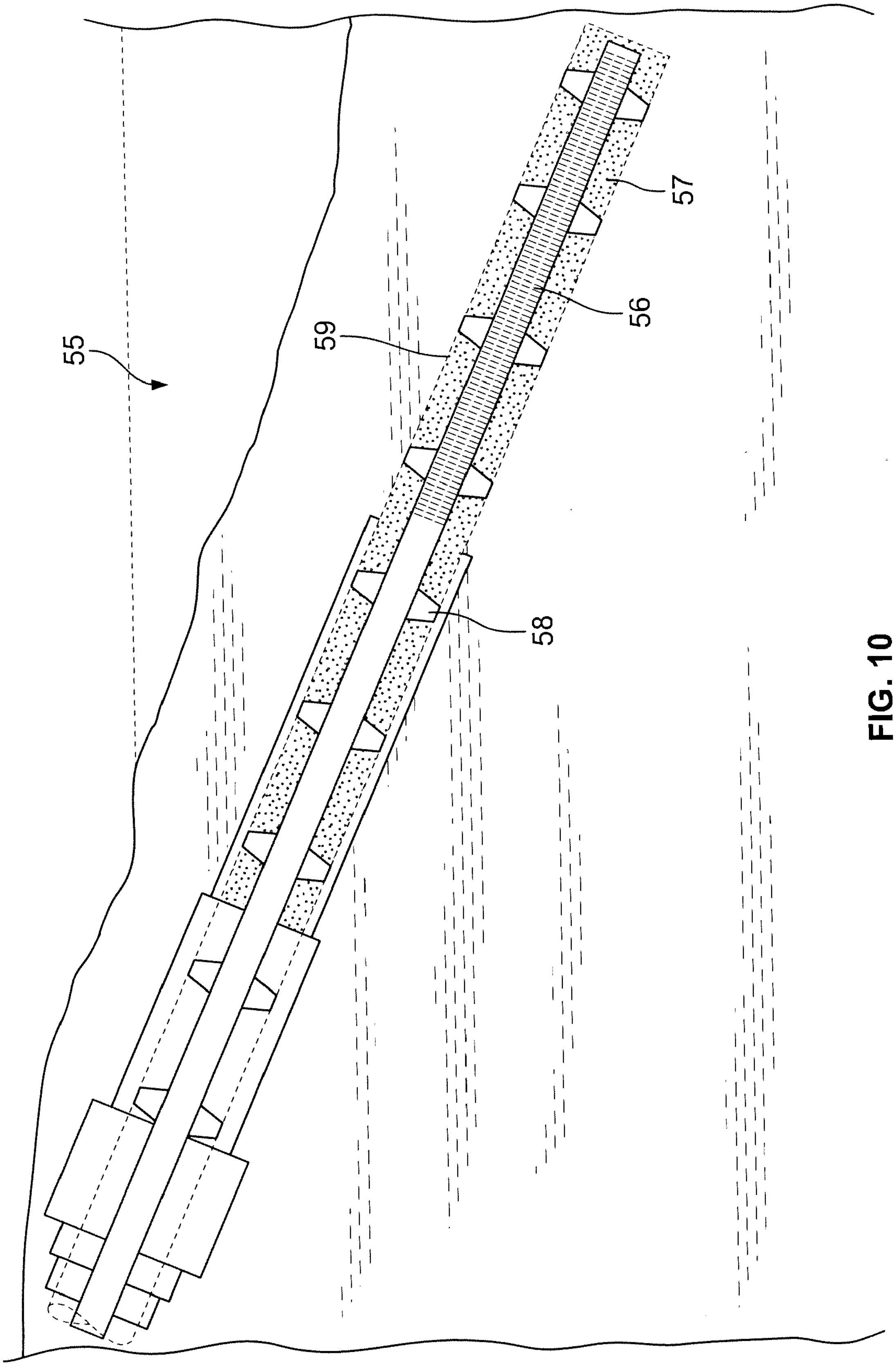


FIG. 10

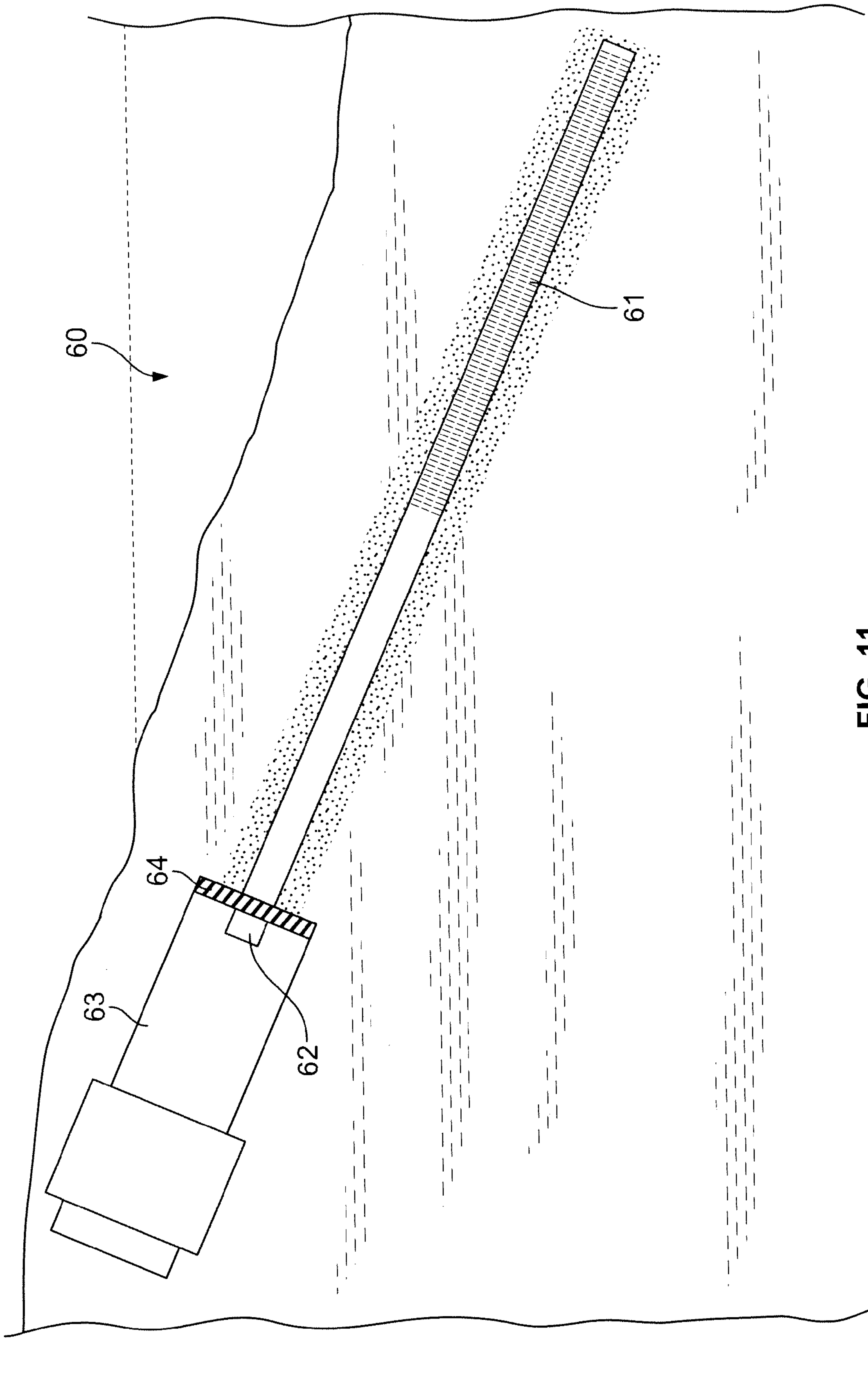


FIG. 11

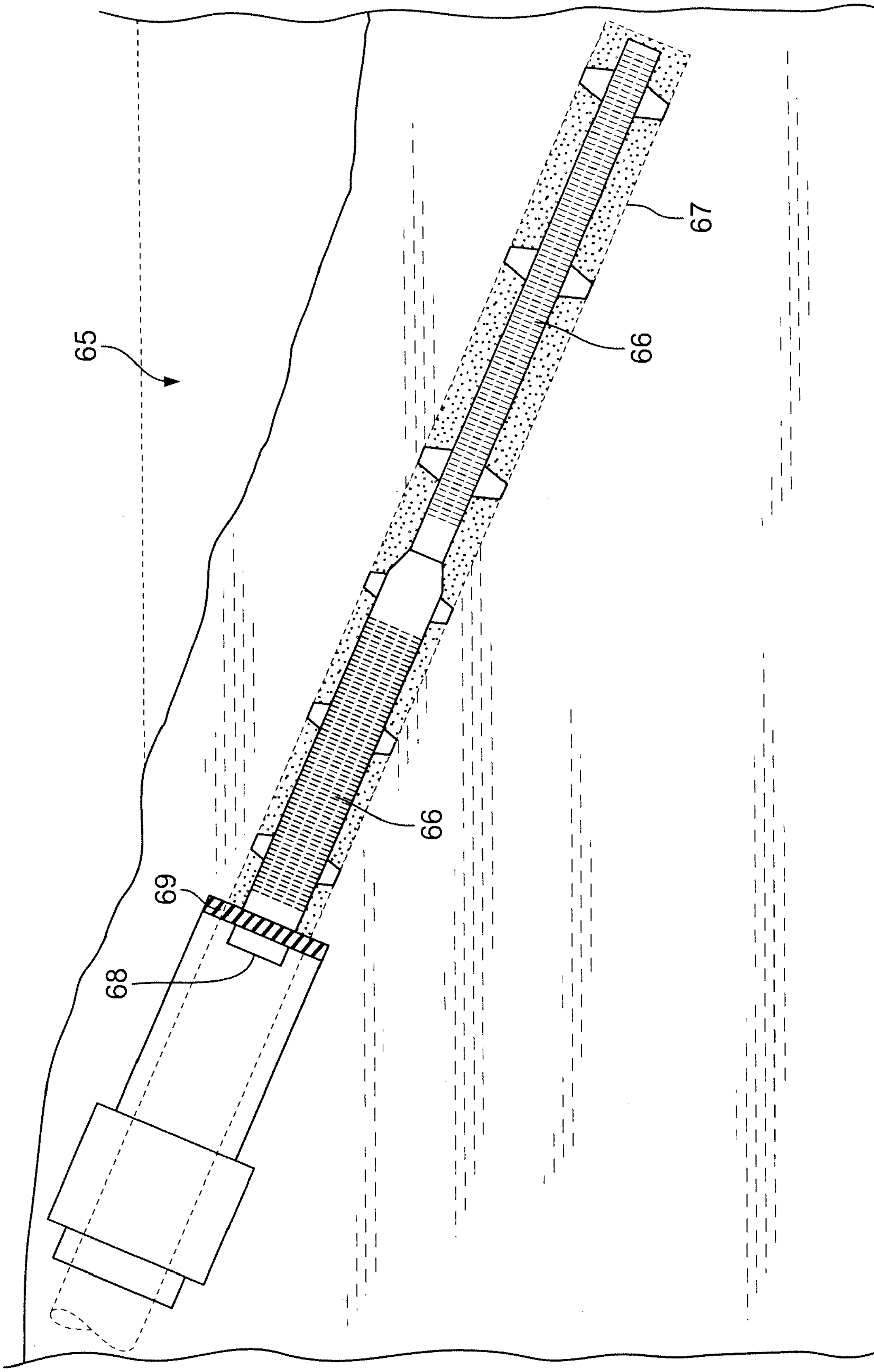


FIG. 12

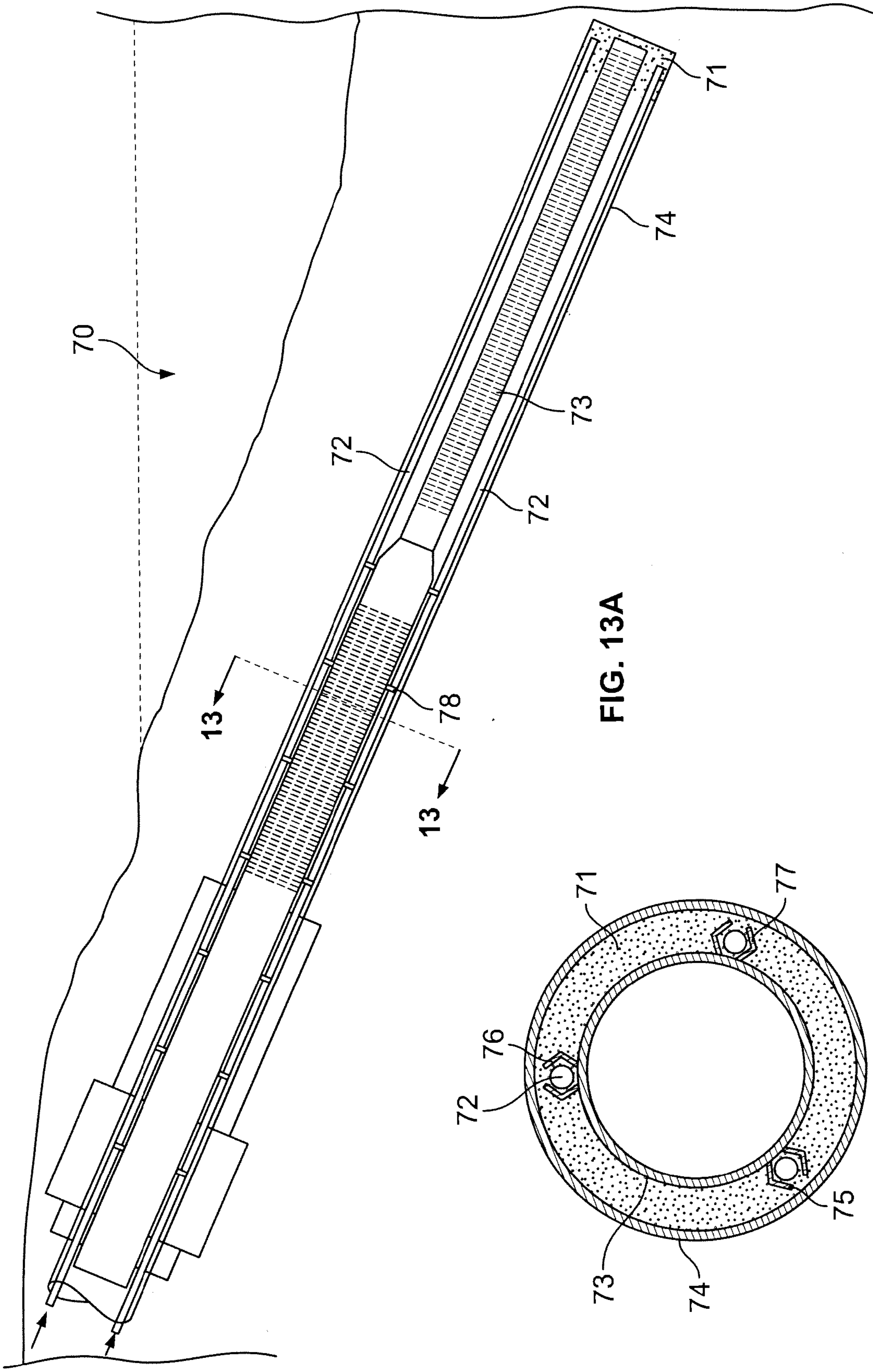


FIG. 13A

FIG. 13B

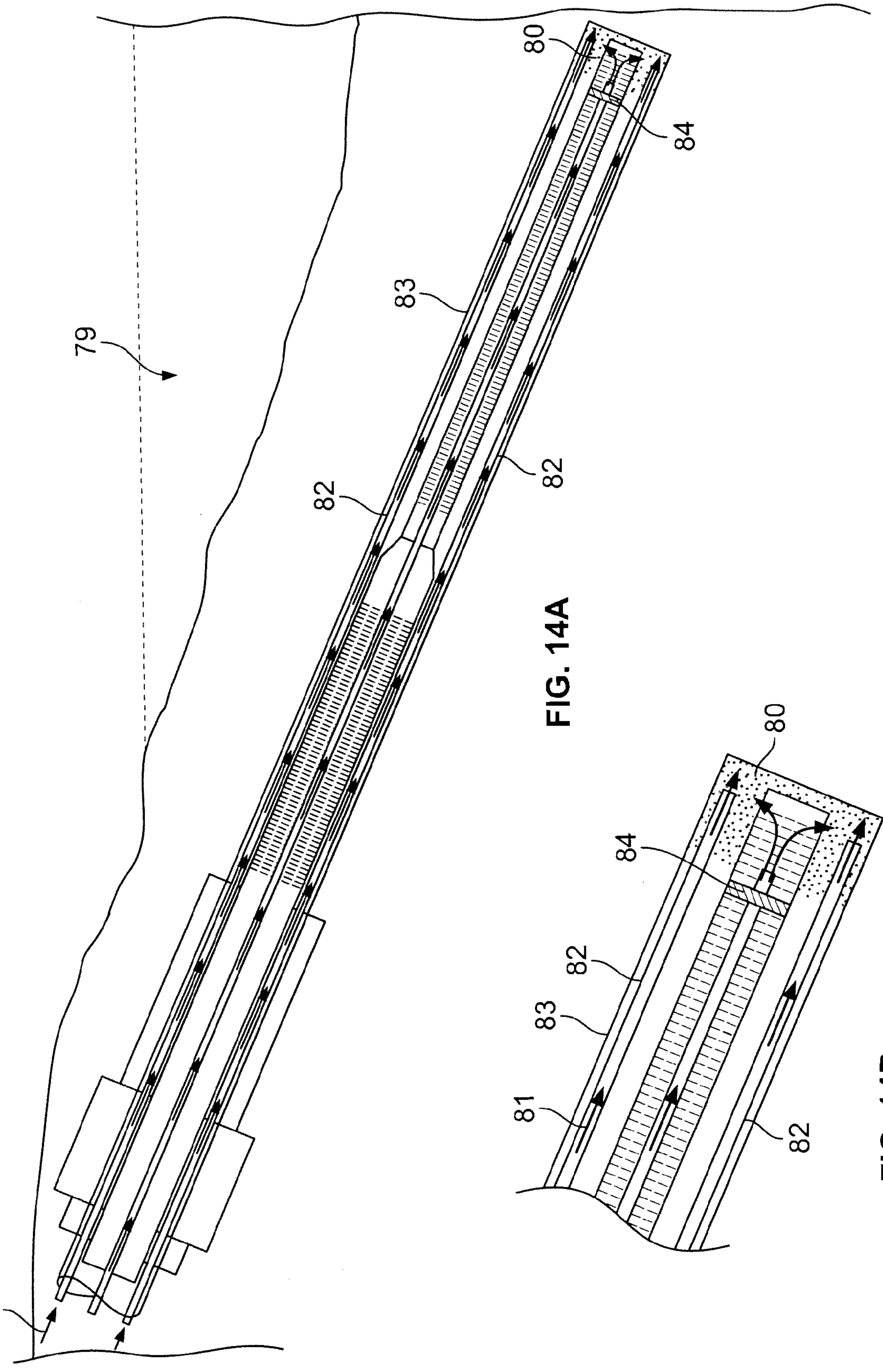


FIG. 14A

FIG. 14B

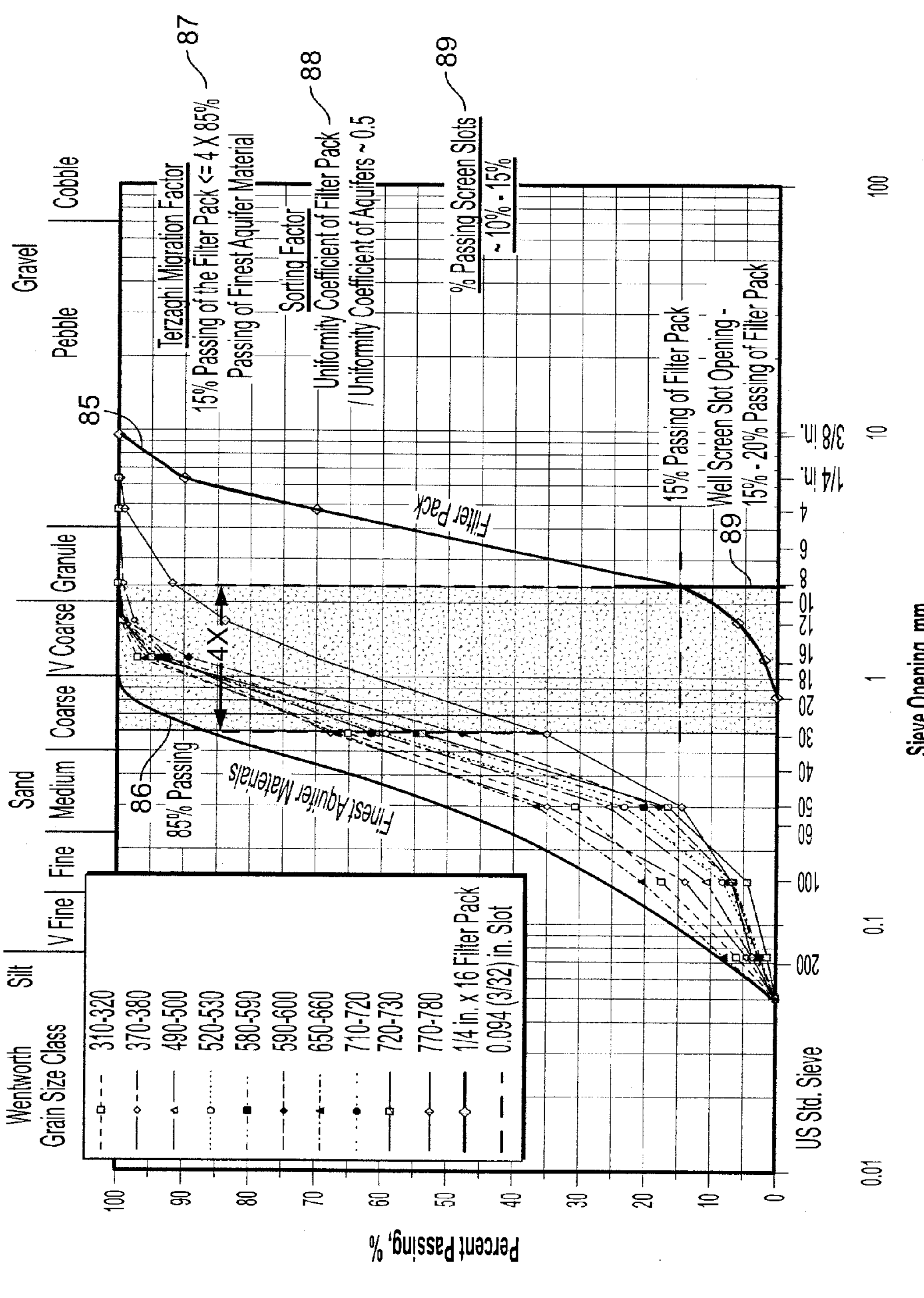

Wentworth Grain Size Class
Silt
V Fine
Fine
Sand
Medium
Coarse
V Coarse
Granule
Pebble
Gravel
Cobble
310-320
370-380
490-500
520-530
580-590
590-600
650-660
710-720
720-730
770-780
1/4 in. x 16 Filter Pack
0.094 (3/32) in. Slot
Terzaghi Migration Factor
15% Passing of the Filter Pack <= 4 X 85%
Passing of Finest Aquifer Material
Sorting Factor
Uniformity Coefficient of Filter Pack
/ Uniformity Coefficient of Aquifers ~ 0.5
% Passing Screen Slots
~ 10% - 15%
87
88
89
85
86
85% Passing
4X
Finest Aquifer Materials
Filter Pack
15% Passing of Filter Pack
Well Screen Slot Opening -
15% - 20% Passing of Filter Pack
Percent Passing, %
100
90
80
70
60
50
40
30
20
10
0
US Std. Sieve
200
100
60
50
40
30
20
18
16
12
10
8
6
4
1/4 in.
3/8 in.
0.01
0.1
1
10
100
Sieve Opening, mm

FIG. 15

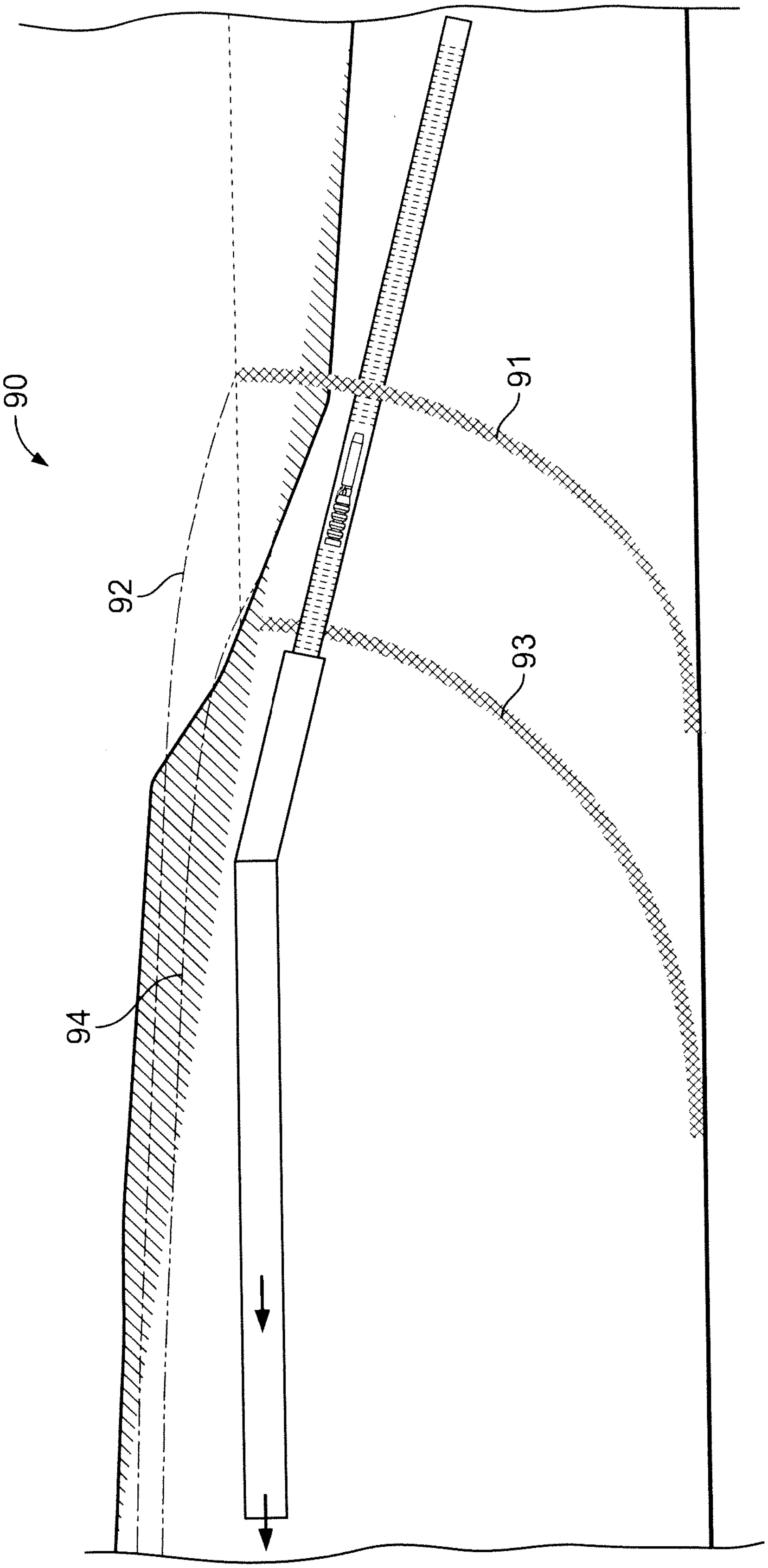


FIG. 16

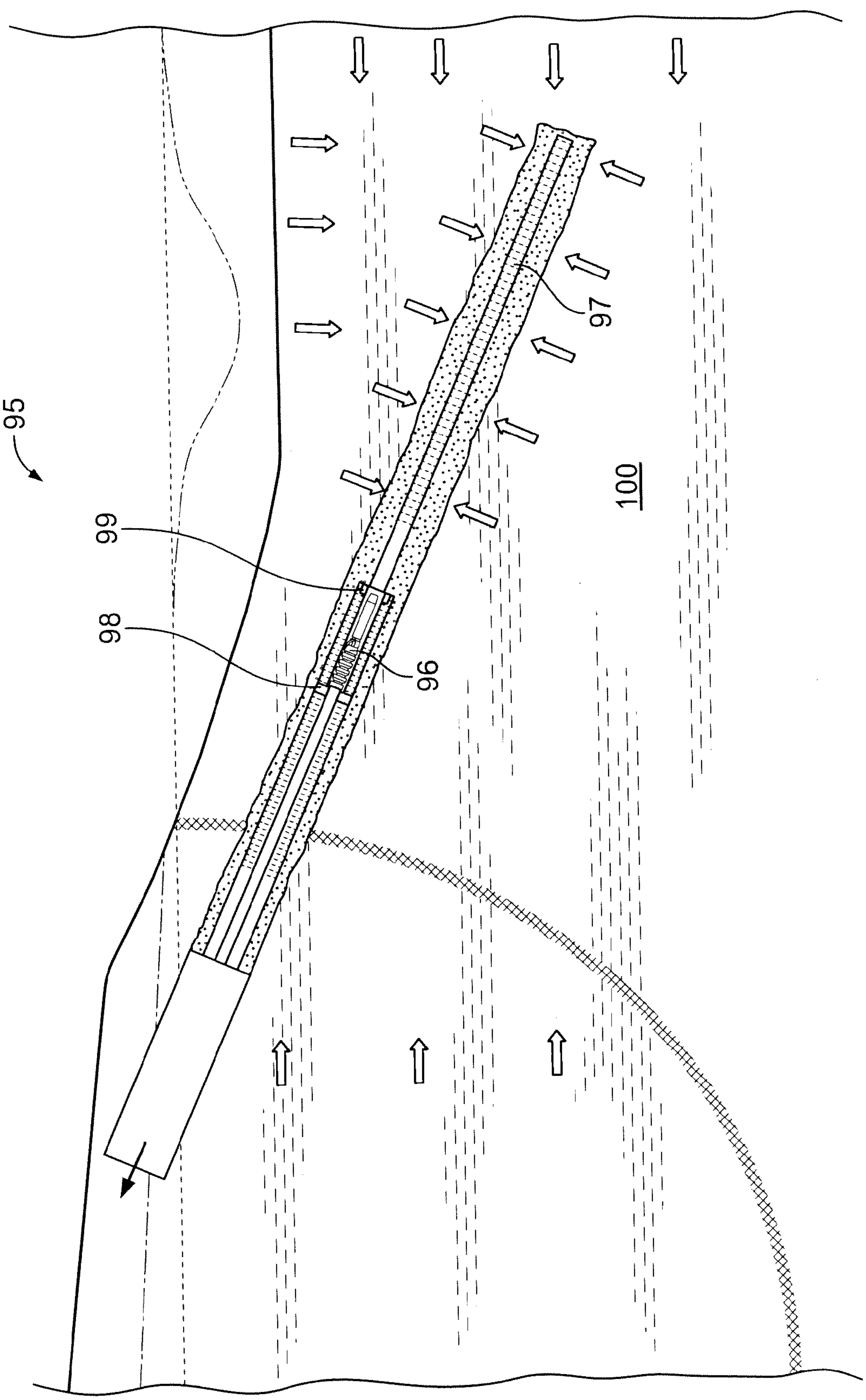


FIG. 17

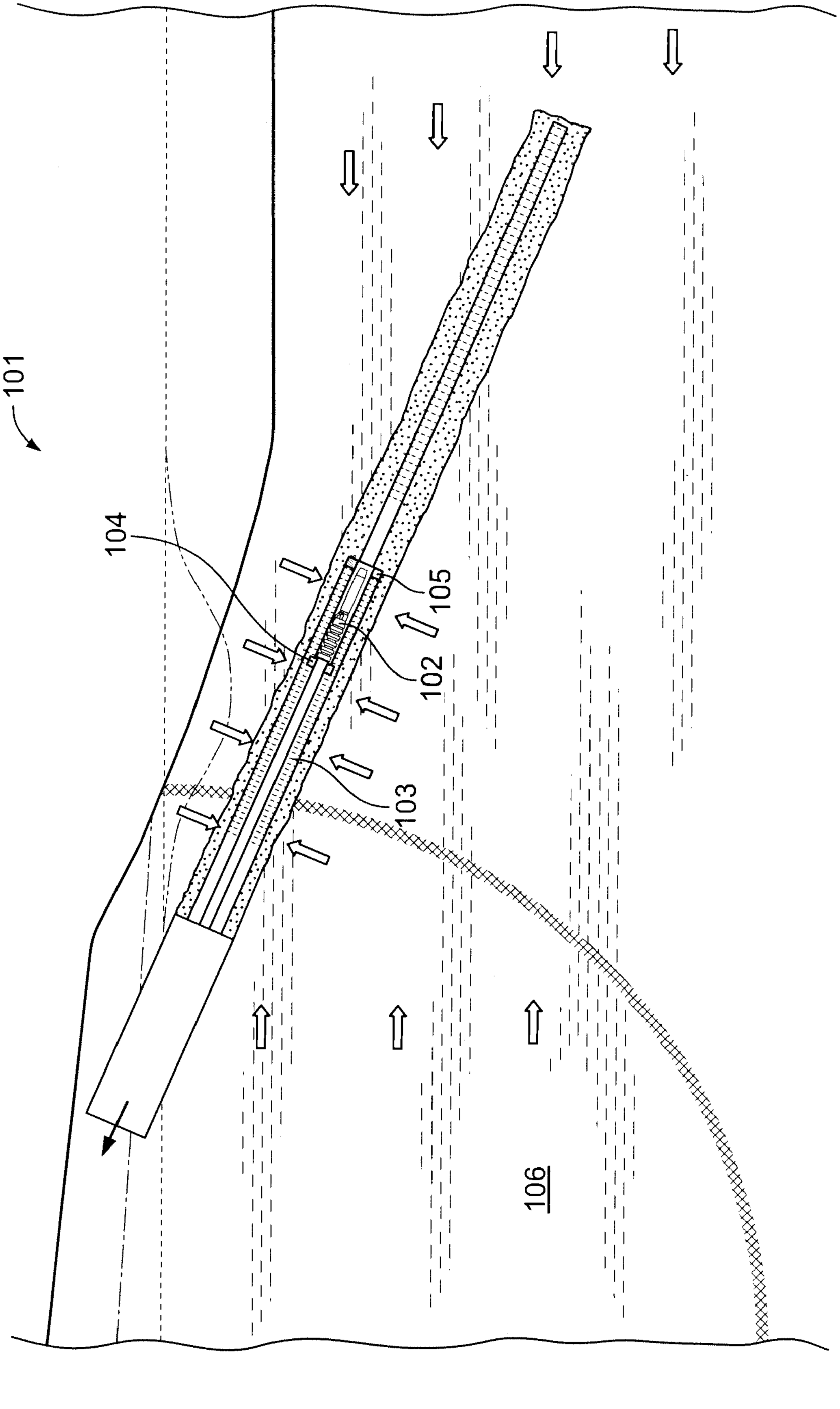


FIG. 18

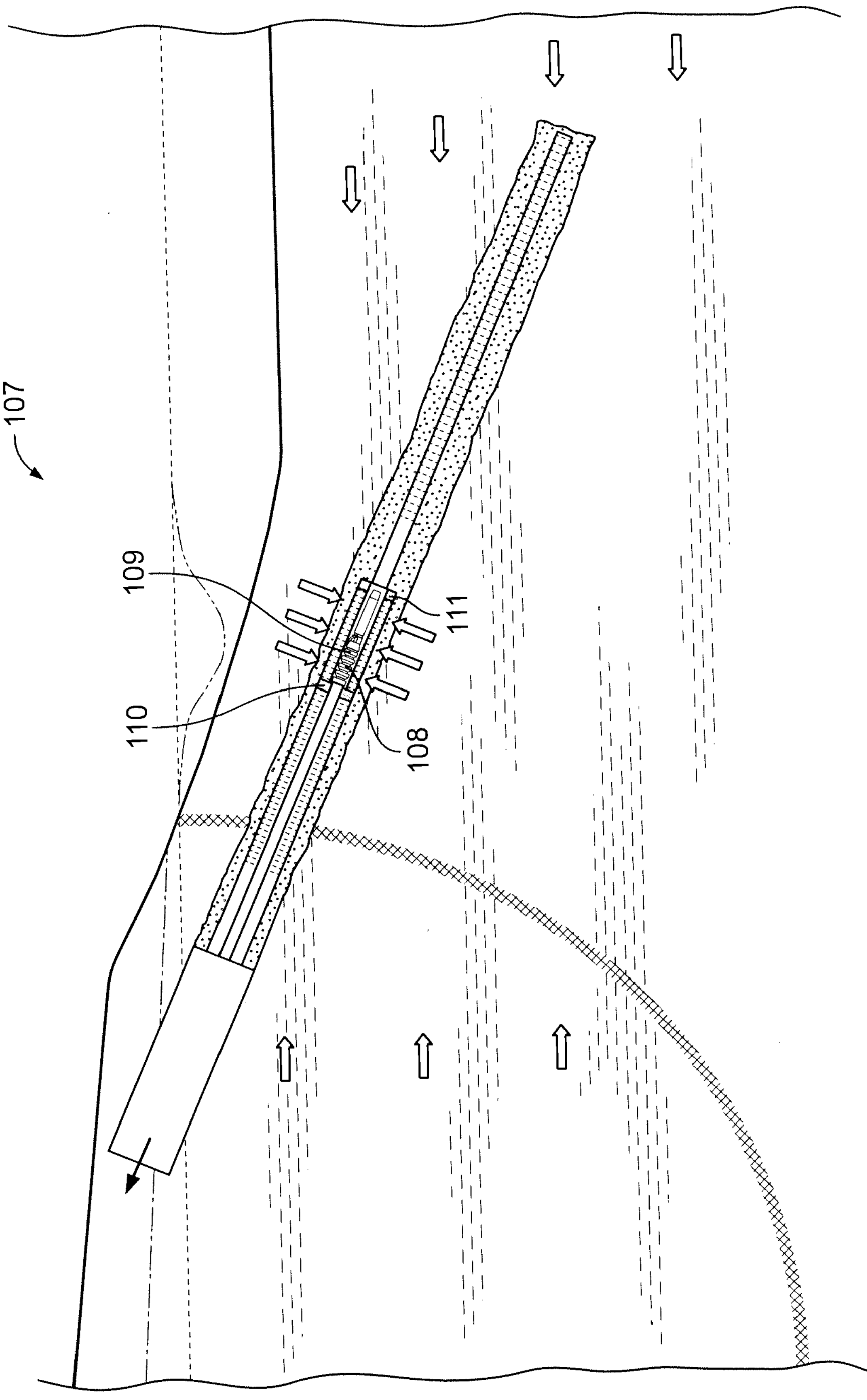


FIG. 19

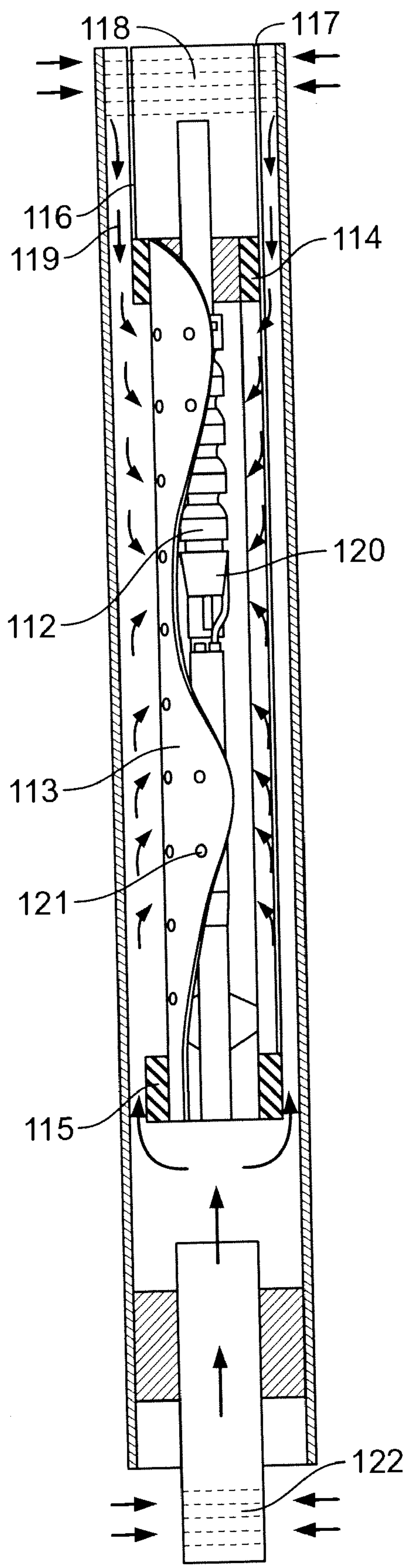


FIG. 20

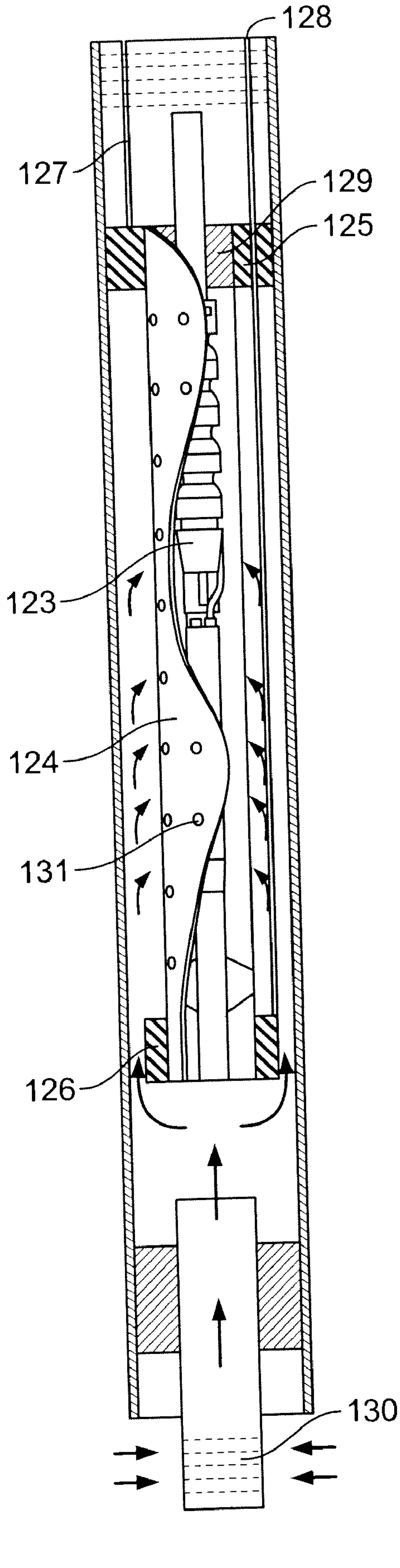


FIG. 21

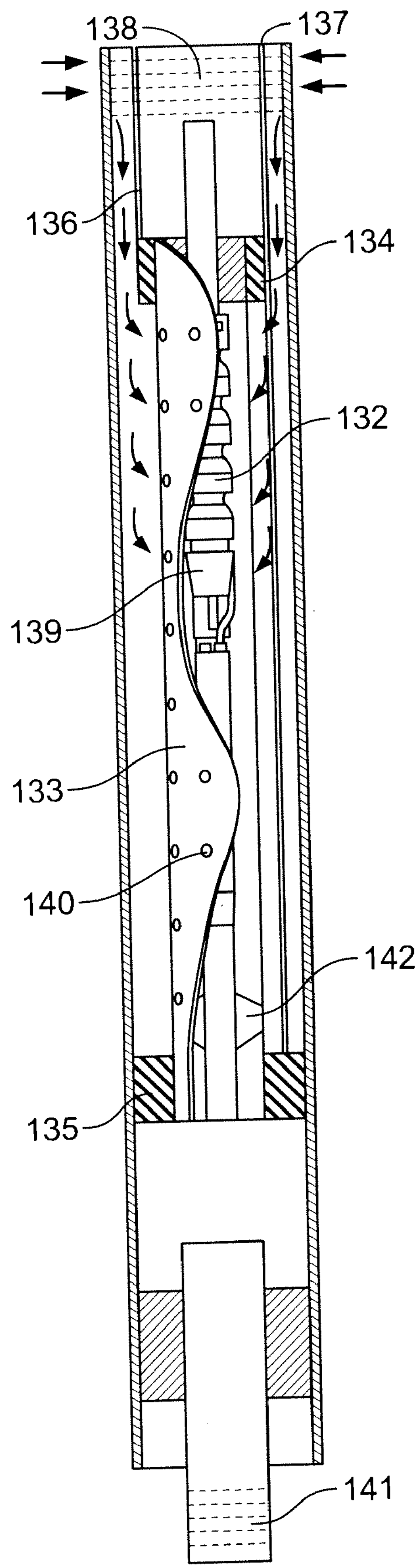


FIG. 22

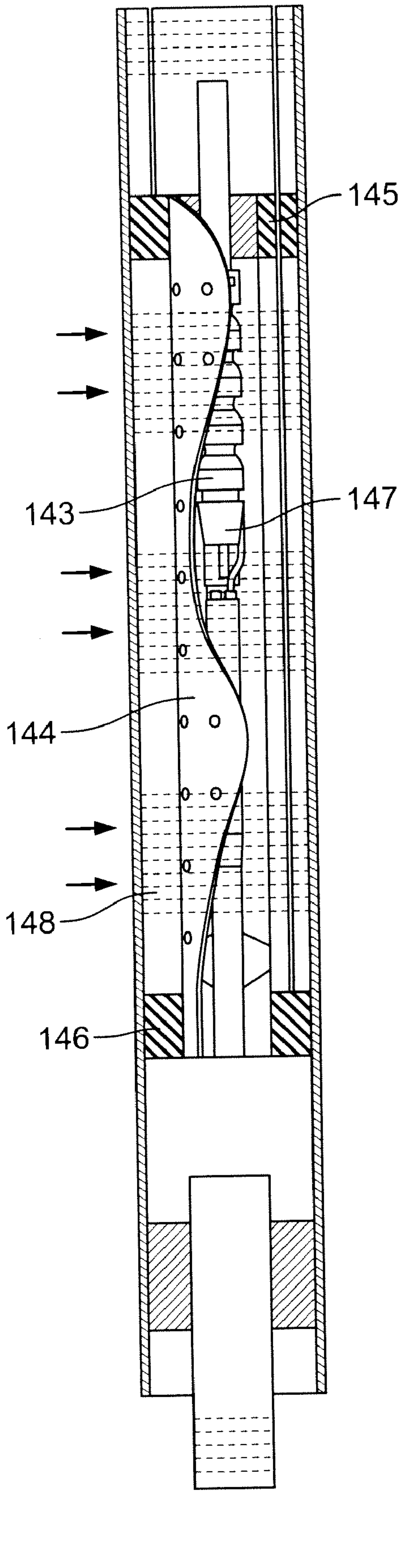


FIG. 23

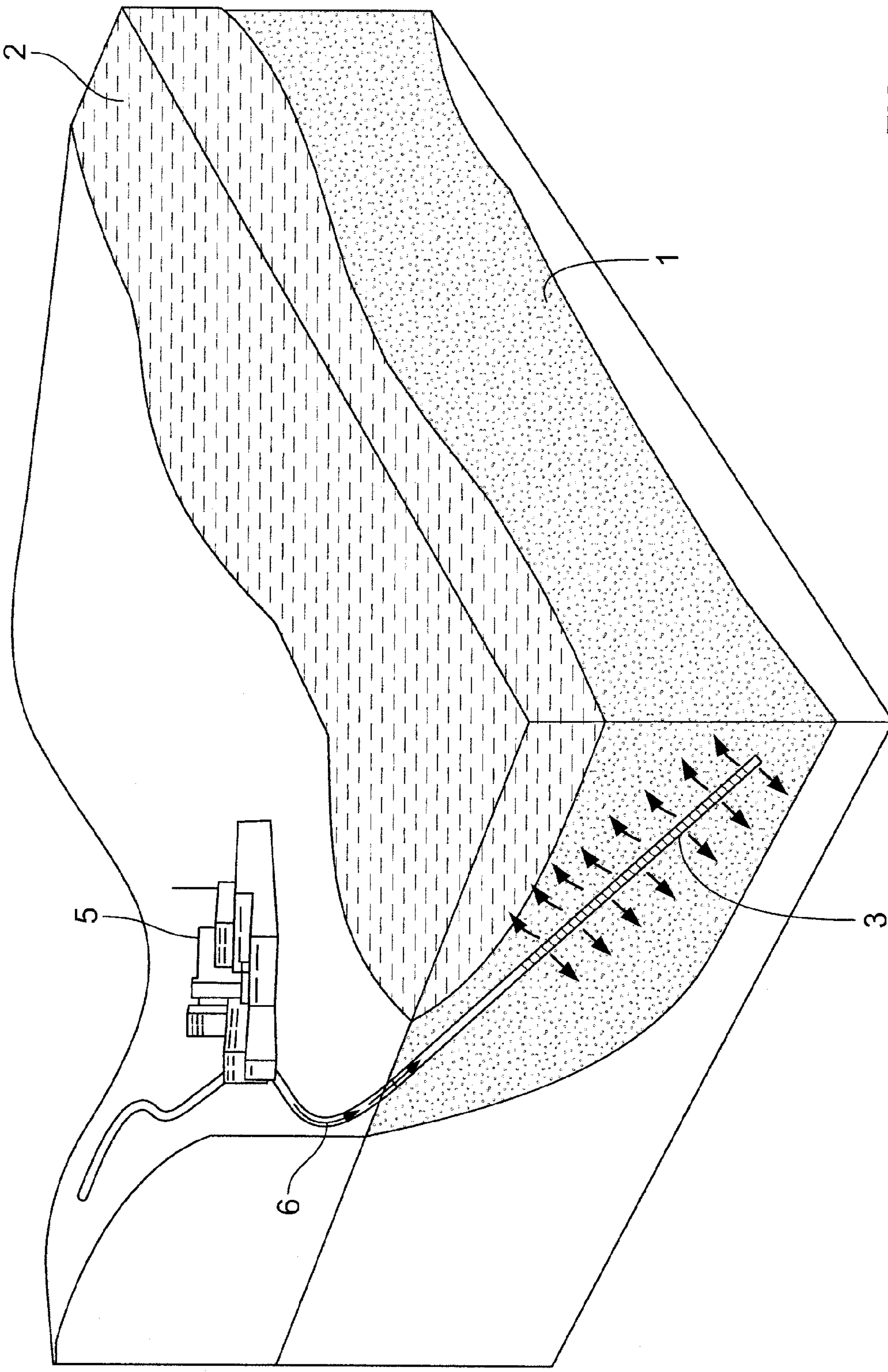


FIG. 24

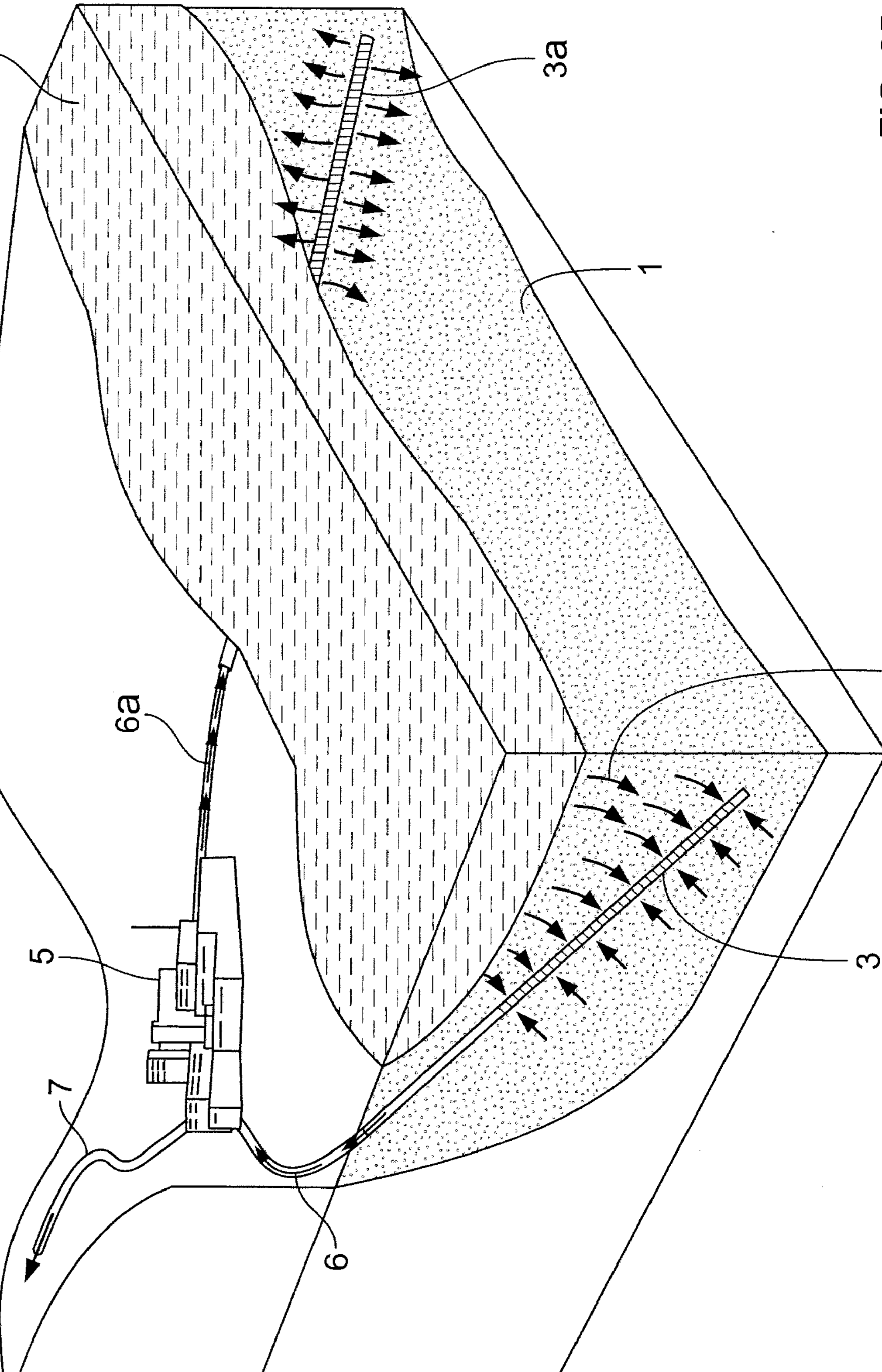


FIG. 25

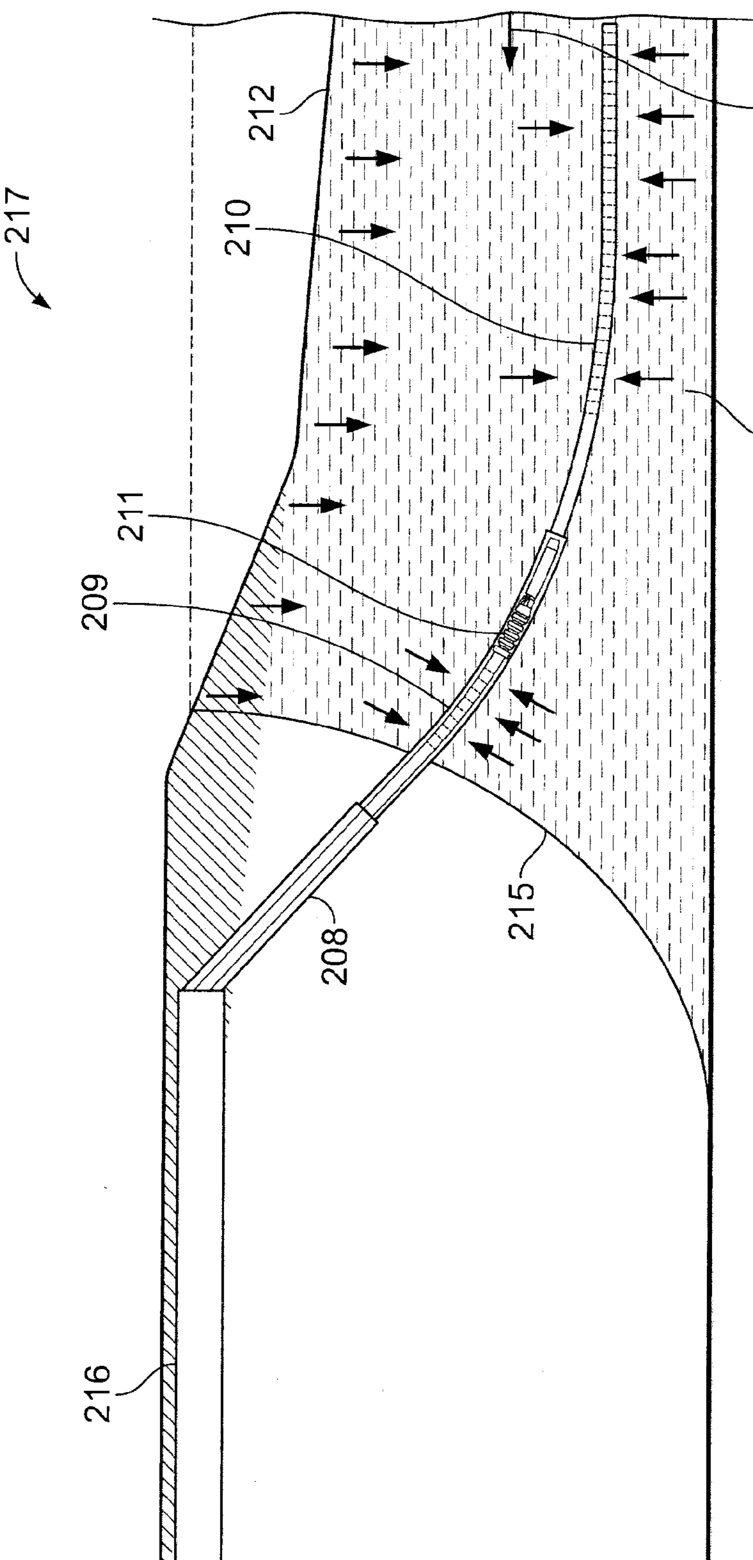


FIG. 26

DESALINATION SUBSURFACE FEEDWATER SUPPLY AND BRINE DISPOSAL

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This is a continuation-in-part of U.S. application Ser. No. 12/748,886, filed by Dennis E. Williams on Mar. 29, 2010, which claims priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 61/293,134, filed by Dennis E. Williams on Jan. 7, 2010. Priority is claimed to these applications, the entire contents of which are herein incorporated by reference.

FIELD OF THE INVENTION

[0002] The invention relates generally to the field of supplying water from subsurface intake systems to desalination plants and concentrate disposal (e.g., injection of brine). More specifically, the invention relates to the construction of slant well systems or horizontally directionally drilled ("HDD") well systems to supply water from near-shore or subsea aquifers to desalination plants and to inject concentrate (e.g., desalination process brine) into subsea aquifers.

BACKGROUND OF THE INVENTION

[0003] Water developers in California and other coastal communities throughout the world are increasingly considering seawater desalination as a potential source of water for municipal and industrial supply. Limited ground water supplies in the coastal areas, poor inland ground water quality, and decreasing reliability of imported water have made seawater desalination a viable consideration. Seawater desalination has been made even more viable through more cost-effective and efficient subsurface intake systems and water treatment technologies.

[0004] Slant well drilling is included in the practice of drilling non-vertical wells. Non-vertical wells are typically used in the petroleum industry and are also known as horizontally directionally drilled wells (HDD wells). Slant wells are also used in other applications, such as drilling beneath roadways or rivers in order to provide conduits for facilities. Slant well desalination subsurface intake systems present significant advantages over traditional open water desalination plant intakes. These advantages include avoidance of entrainment and impingement impacts to marine life, reduction or elimination of costly reverse osmosis pretreatment, and reduction or elimination of permanent visual impacts. Slant well systems are buried systems (i.e. there are little or no visual impacts on the surface), as the wells and connecting pipelines are typically completed below the land surface.

[0005] In the past, slant well technology has not been successfully applied to subsea construction of desalination feedwater supplies, as the well screen slots have become clogged during pumping. Once the well screen slot openings are clogged, it becomes difficult or impossible to continue to pump water. Accordingly, there is a need for a reliable slant well system that is able to supply water from near-shore or subsea aquifers to a desalination plant without becoming clogged with fine-grained materials (e.g., fine sands and silts) over time. There is also a need for a method of constructing such a system—especially at low angles below horizontal in order to minimize impacts to inland fresh water sources. The present invention satisfies these needs and provides further related advantages, especially with regard to regulation of feedwater salinity.

SUMMARY OF THE INVENTION

[0006] The present invention is embodied in a system for supplying water to a desalination plant from a subsurface feedwater supply using one or more slant wells. The present invention is also embodied in a method for constructing a slant well feedwater supply system for supplying water from a subsurface feedwater supply. A system of angled wells (slant wells) is constructed. In one embodiment, the slant wells obtain a desalination feedwater supply from permeable aquifer systems near and/or beneath a saline water source (i.e., an ocean, sea, or salty inland lake). The slant wells induce recharge of the aquifer system through the floor of the ocean, sea, or inland lake due to the hydraulic head difference between the slant well pumping level and the level of the ocean, sea, or lake. As the supply source is relatively constant, the water supply to such a slant well system generally provides a long-term, sustainable water source for a desalination plant. The slant wells may be constructed at angles that vary from zero to ninety degrees below horizontal.

[0007] In one embodiment, the systems and methods discussed here are different from other non-vertical well applications in that they include an engineered, artificially filter-packed, angled well designed specifically to produce a high-capacity, low-turbidity desalination plant feedwater supply source from near-shore and offshore subsurface aquifer systems.

[0008] In one embodiment of the invention, the slant wells include a unique telescoping set of casings and screens. This design allows for a larger pump house casing near the land surface, with successively smaller casing and screen diameters as the well extends downward. The telescoping casings and screens facilitate extending the well to lineal lengths of 1,000 feet or greater beneath the floor of the saline water body, with angles below horizontal ranging from zero to ninety degrees.

[0009] In other, more detailed features of the invention, the slant well feedwater supply system may comprise a single slant well, an array of two or more slant wells, or multiple arrays of two or more slant wells, the location, spacing, and geometric layout of which may vary among feedwater intake sites depending upon the geohydrologic extent (horizontal and vertical) and characteristics of the subsurface aquifer materials, as well as upon the subsurface aquifer system salinity variation.

[0010] In another embodiment of the invention, an engineered artificial filter pack is placed around the well screen portions of the slant wells through a multi-step process that includes:

[0011] a. Placing the artificial filter pack in the annular space between the well screen and a temporary casing by pumping the filter pack material under pressure through one or more movable tremie pipes;

[0012] b. Placing a movable or temporary packer or blocking assembly within the bore of the well screen section near the portion of the well where the artificial filter pack is being placed;

[0013] c. Pumping water through the center of the well-screen packer assembly so that the water exits the well screen below the packer assembly and travels out of the well screen into the filter pack (water injection through the well-screen packer assembly helps to settle the filter pack, as well as ensure that the filter pack completely surrounds the well screen in the annular space between the well screen and the temporary casing);

[0014] d. Slowly withdrawing the tremie pipes and well-screen packer assembly up the screened portion of the well so that the artificial filter pack is placed along the length of the screened portion; and

[0015] e. Simultaneously withdrawing the temporary casing surrounding the well screen and filter pack by pulling, rocking and/or vibrating the casing.

[0016] Placement of the engineered artificial filter pack around the screened portions of the slant well helps stabilize the subsea aquifer materials and prevent migration of fine sand and silt materials (from subsea aquifers) into the well. This both inhibits the screen portions from becoming clogged and results in a desalination feedwater water quality, as measured by turbidity and silt density indices (a measure of fouling in reverse osmosis desalination systems), that eliminates or minimizes the need for pre-treatment of the water prior to desalination.

[0017] In one embodiment, the well screens are centered inside the temporary casings through a system of centralizers or screen centering guides.

[0018] The present invention is also embodied in a method of minimizing variations in feedwater salinity, the method comprising providing a plurality of slant wells, each having a different angle below horizontal. Shallower-angled wells tend to produce water having greater salinity, whereas steeper-angled wells tend to produce water having lesser salinity. By varying the amounts of water pumped from shallower-angled wells versus steeper-angled wells, variations in feedwater salinity that occur due to natural variations in the hydrologic cycle can be minimized. Natural variations in the hydrologic cycle (such as wet and dry hydrologic periods) can impact the location of the freshwater-saltwater interface due to variations in fresh water flowing from the land to the ocean, sea, or inland lake.

[0019] On one embodiment, multiple well screens are placed in a single slant well to minimize variations in feedwater salinity in that well that occur due to natural variations in the hydrologic cycle. The slant well can be equipped with a submersible pumping system fitted with a dual-packer shroud assembly. Using the dual-packer shroud assembly, the slant well can selectively pump from upper or lower portions of the subsea aquifer, thereby varying feedwater salinity as required to help minimize variations in feedwater salinity due to hydrologic cycles. The dual-packer shroud assembly (DPSA) allows selective production from well screens both above and below the packers (maximum production), well screens above the upper packer only (lower salinity), well screens below the lower packer only (higher salinity), or well screens between the packers (focused salinity).

[0020] Embodiments of the present invention include a telescoping slant well feedwater supply system for supplying water from an aquifer. The system comprises a primary well screen for admitting water from the aquifer (the primary well screen oriented along an axis angled below horizontal and having a substantially uniform cross-sectional area); a filter pack substantially surrounding the primary well screen; a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and a submersible pump contained within the pump house casing for pumping water admitted through the primary well screen. The cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

[0021] In another embodiment, the axis is straight. The system may further comprise a secondary well screen for admitting water from the aquifer, the secondary well screen oriented along the same axis but having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen. The system may additionally comprise a dual-valve assembly contained within the pump house casing. The dual-valve assembly may comprise a first valve for regulating the flow of water from the primary well screen to the submersible pump, and a second valve for regulating the flow of water from the secondary well screen to the submersible pump. In one embodiment, the first valve is a first pneumatic packer, and the second valve is a second pneumatic packer. The system may further comprise a first air line configured to extend from an air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer, and a second air line configured to extend from an air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer. The system may additionally comprise a tertiary well screen for admitting water from the aquifer, the tertiary well screen oriented along the axis between the first valve and the second valve. The dual-valve assembly may further comprise a shroud substantially surrounding the submersible pump. The shroud may have a plurality of holes through which water from the primary or secondary well screens can flow to the submersible pump. The dual-valve assembly may further comprise centering guides attached to the shroud for centering the submersible pump within the shroud.

[0022] Embodiments of the present invention also include a method of constructing a slant well feedwater supply system for supplying water from an aquifer. The method comprises the steps of placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings; placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings; and placing a filter pack in the space between the well screen and the one or more temporary casings.

[0023] In one embodiment, the method further comprises the step of withdrawing the one or more temporary casings. The step of placing the well screen may comprise the step of centering the well screen within the one or more temporary casings using centering guides. In the step of placing a telescoping plurality of casings, the telescoping plurality of casings may comprise a pump house casing. In one embodiment, the pump house casing has an upward end and a downward end, and the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing along the axis. The method may further comprise the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

[0024] In another embodiment, the step of placing the filter pack comprises the steps of extending one or more tremie pipes to the space between the well screen and the one or more temporary casings, and pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings. The step of extending the one or more tremie pipes may comprise the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides. In one embodiment, the one or more tremie pipes consist of three tremie pipes, and the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen. The step of placing the filter pack may further comprise the steps of placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer, and pumping water through the water pipe to settle the filter pack material. The method may further comprise the step of withdrawing the packer assembly and the one or more tremie pipes. The steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes may be gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

[0025] Embodiments of the present invention also include a method for reducing salinity variation in feedwater supplied from a slant well system comprising an upper well screen and a lower well screen for admitting water from an aquifer, a submersible pump for pumping water admitted through the upper or lower well screens, an upper valve for regulating water flow from the upper well screen to the submersible pump, and a lower valve for regulating water flow from the lower well screen to the submersible pump. The method comprises the steps of controlling the upper valve to inhibit water flow from the upper well screen to the submersible pump if the salinity of the feedwater decreases below a first predetermined threshold, and controlling the lower valve to inhibit water flow from the lower well screen to the submersible pump if the salinity of the feedwater increases above a second predetermined threshold. In one embodiment, the upper valve, in the step of controlling the upper valve, is a first pneumatic packer, and the lower valve, in the step of controlling the lower valve, is a second pneumatic packer.

[0026] The embodiments described above may alternatively be implemented using an HDD well.

[0027] In another exemplary system that embodies the invention, use of the slant or HDD wells can be used to dispose of water or brine that results from the desalination process. In one embodiment, construction of the slant or HDD well would be the same regardless of its use (extraction well or injection well) and would employ the same method of construction and placement of an artificial filter pack. In some conditions where the subsea aquifer does not require an engineered artificial filter pack, a natural filter pack comprising naturally occurring native (i.e., in situ) materials could be developed around the well screen portions of the slant or HDD well for the extraction (feedwater supply) or injection (concentrate return) process.

[0028] Other features of the invention should become more apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] Various embodiments of the present invention will now be described, by way of example only, with reference to the following drawings.

[0030] FIG. **1** is an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to an inland desalination plant, in accordance with an embodiment of the present invention. This embodiment may alternatively be implemented using an HDD well.

[0031] FIG. **2** is a side elevation view of a telescoped slant well having upper and lower well screens and showing water infiltration from the ocean and the freshwater-saltwater interface, in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casing cut away to show a submersible pump inside the pump house casing.

[0032] FIG. **3** is a side elevation view of a telescoped slant well having a single well screen interval and showing primary and secondary sources of water recharge to the slant well, in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screen shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing.

[0033] FIG. **4** is a side elevation view of a telescoped slant well having multiple screened intervals, in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing fitted with a dual-packer shroud assembly having both packers deflated for maximum well production.

[0034] FIGS. **5**A-**5**D are top plan views of four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration, a two-well array, a three-well array, and a four-well array, in accordance with embodiments of the present invention.

[0035] FIGS. **6**A and **6**B are top plan views of two slant well configurations, each having separate well head areas for the slant wells in the configuration, in accordance with embodiments of the present invention.

[0036] FIG. **7** is a side elevation view showing two telescoped slant wells extending from a common well head but at different angles below horizontal to produce water having different salinities (higher salinity production from the shallower-angle slant well and lower salinity production from the steeper-angle slant well), in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casings cut away to show submersible pumps inside the pump house casing.

[0037] FIG. **8** is a side elevation view of a telescoped slant well having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention.

[0038] FIG. **9** is a side elevation view of a telescoped slant well showing the placement of a single screened section centered within a temporary casing using centering guides and surrounded by an artificial filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

[0039] FIG. **10** is a side elevation view of a telescoped slant well illustrating the removal of the 20-inch diameter temporary casing surrounding the well screen and filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

[0040] FIG. **11** is a side elevation view of a telescoped slant well having a single screened section with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the filter pack cut away to show the well screen.

[0041] FIG. **12** is a side elevation view of a telescoped slant well having dual screened intervals with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the centering guides and filter pack cut away to show the well screen.

[0042] FIG. **13**A is a side elevation view of a telescoped slant well showing the placement of an artificial filter pack through a system of multiple tremie pipes in the annular space between the lower well screen and the temporary casing, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the tremie pipies and upper and lower well screens. FIG. **13**B is a cross-section view of the telescoped slant well of FIG. **13**A, taken along the line **13-13** in FIG. **13**A, showing the temporary casing, upper well screen, filter pack, tremie pipes, and tremie pipe guides.

[0043] FIG. **14**A is a side elevation view of a telescoped slant well showing the placement and settlement of an engineered artificial filter pack through a multi-step process of placing the filter pack by pumping filter pack material through tremie pipes under pressure, simultaneously removing the temporary casing surrounding the tremie pipes, settling the filter pack using an in-screen packer assembly, and gradually withdrawing the in-screen packer assembly, in accordance with an embodiment of the present invention, with the casings and well screens cut away to show the in-screen packer assembly. FIG. **14**B is a detail view of the telescoped slant well of FIG. **14**A, showing the filter pack placement.

[0044] FIG. **15** is a chart of sieve opening versus percent of filter material passing the well screen slots for designing an engineered filter pack from site-specific samples of aquifer materials.

[0045] FIG. **16** is a side elevation view of a multiple-screened, telescoped slant well showing how the slant well can pump water with higher or lower salinity because of variations in the freshwater-saltwater interface due to natural variations in the hydrologic cycle, in accordance with an embodiment of the present invention, with the pump house casing cut away to show a submersible pump inside the pump house casing.

[0046] FIG. **17** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the lowermost screen only (upper packer inflated, lower packer deflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

[0047] FIG. **18** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the uppermost screen only (upper packer deflated, lower packer inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

[0048] FIG. **19** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the well screen portion between the dual packers (upper and lower packers inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

[0049] FIG. **20** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for maximum production (both upper and lower packers deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

[0050] FIG. **21** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from below the lower packer (upper packer inflated and lower packer deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

[0051] FIG. **22** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from above the upper packer (upper packer deflated and lower packer inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

[0052] FIG. **23** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from between the dual packers (both upper and lower packers inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

[0053] FIG. **24** is an isometric block drawing illustrating a slant or HDD well concentrate disposal system injecting water or brine from a desalination plant into a subsurface aquifer system below the ocean floor.

[0054] FIG. **25** is an isometric block drawing illustrating a slant or HDD well feedwater supply system and a slant or HDD well concentrate disposal system.

[0055] FIG. **26** is a side elevation view of a telescoped HDD well, in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casing cut away to show a submersible pump inside the pump house casing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0056] The invention is generally embodied in a slant or HDD well, or system of slant or HDD wells, that produces water from permeable deposits near or beneath saline water bodies (e.g., oceans, seas, or inland lakes) or injects concentrate return into deposits beneath saline water bodies. The invention can provide a long-term, sustainable feedwater supply for a desalination plant with virtually unlimited recharge potential.

[0057] With reference now to the illustrative drawings, and particularly to FIG. **1**, there is shown an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to a desalination plant, in accordance with an embodiment of the present invention. Permeable materials comprising the subsea aquifer **1** are recharged from the overlying ocean **2**. The slant well **3** receives recharge from induced infiltration of ocean water **4** and pumps this feedwater to a desalination plant **5** through a pipeline **6**. The desalination plant **5** pumps out freshwater through a freshwater pipeline **7** to meet inland water supply demands.

[0058] FIG. **24** shows a slant or HDD well concentrate disposal system from a desalination plant into subsurface materials. Permeable materials comprising the subsea aquifer **1** receive the injected water from the slant or HDD well **3** (or a plurality of slant or HDD wells). The slant or HDD well **3** injects concentrate return from the desalination plant **5**. The concentrate return is pumped to the slant or HDD injection well **3** through the pipeline **6**.

[0059] FIG. **25** shows a slant or HDD well feedwater supply system and a slant or HDD well concentrate disposal system. Permeable materials comprising the subsea aquifer **1** supply water to the slant or HDD well **3**. Feedwater is pumped to the desalination plant **5** through the pipeline **6**. Desalination concentrate return (e.g., brine) is injected into the subsurface aquifer system **1** via the pipeline **6***a* through the concentrate return injection well (slant or HDD) **3***a*.

[0060] With reference now to FIG. **2**, there is shown a telescoped slant well **8** configured for use in a feedwater supply system **17**, in accordance with an embodiment of the present invention. In one embodiment, the slant well is drilled at a low angle below horizontal using a dual rotary drilling rig or other suitable device to a total lineal length of approximately 1,000 feet or more. In one particular embodiment, the slant well is drilled at an angle of approximately 23 degrees below horizontal. The telescoped slant well has an upper well screen **9** and a lower well screen **10** for admitting water from a saltwater aquifer **14**. A submersible pump **11** pumps water out of the slant well to a desalination plant. The slant well is recharged from induced infiltration of water **13** that flows from the ocean floor **12** and lateral offshore sources through the saltwater aquifer **14**. The saltwater aquifer meets the freshwater aquifer beneath the land surface at a freshwater-saltwater interface **15**. Saline water is pumped from the slant well **8** to the desalination plant via an underground pipeline **16** connected to the buried slant well head. In one embodiment, the buried slant well head is connected to the pipeline **16** via a caisson (not shown) sunk into the land surface.

[0061] The slant well **8** is part of a feedwater supply system **17** that comprises the slant well and the pipeline **16**. Because the slant well is buried beneath the land surface and ocean floor, the feedwater supply system avoids entrainment and impingement impacts to marine life. Additionally, the filtration process performed by the subsurface aquifer **14** reduces or eliminates costly reverse osmosis pretreatment that would otherwise need to be performed at a desalination plant. Furthermore, because the slant well is completed below the land and ocean surface, aesthetic impacts are minimized or eliminated.

[0062] FIG. **26** shows a telescoping HDD well system **208** completed with two screen sections **209** and **210**. The submersible pump **211** pumps water from the well, which is recharged from induced infiltration from the ocean floor **212** and lateral off-shore sources **213** that flow into the salt water aquifer **214**. The fresh water-salt water interface is shown by the number **215**. Saline water is pumped from the HDD well **208** to the desalination plant via the pipeline **216**. The HDD well feedwater supply system **217** avoids entrainment and impingement impacts to marine life. In addition, the filtration process of the subsurface aquifer materials **214** reduces or eliminates costly reverse osmosis pretreatment. Furthermore, the HDD well system may be completed below the land surface to eliminate aesthetic impacts.

[0063] Various configurations of a slant well for use in a feedwater supply system will now be described in more detail. With reference to FIG. **3**, there is shown a telescoped slant well **18** having an artificial filter pack **19** and a single well screen interval **20** in accordance with an embodiment of the present invention. The slant well extends through the freshwater-saltwater interface **21**. A primary recharge flow **22** and secondary recharge flow **23** provide recharge to the slant well. Sustained recharge to the slant well is largely provided by induced recharge from the ocean through the primary recharge flow **22** due to the hydraulic head difference between the ocean level **24** and the slant well pumping level **25**. The location of the freshwater-saltwater interface **21** is governed by the height of the freshwater elevation **26**.

[0064] A slant well in accordance with the present invention can have multiple screened intervals for providing greater flexibility in feedwater production. With reference to FIG. **4**, there is shown a telescoped slant well **27** having an artificial filter pack **28**, multiple screened intervals **29** (upper and lower), and a submersible pump **30** fitted with a dual-packer shroud assembly, in accordance with an embodiment of the present invention. In the configuration shown in FIG. **4**, both of the dual packers are deflated so that water is drawn into the well through both the upper and lower screened intervals. This configuration is for maximum feedwater production. In other configurations, one or both of the dual packers can be inflated so that water is drawn into the well through less than the full length of the screened intervals. These other configurations are described in greater detail below with respect to FIGS. **17-23**.

[0065] A feedwater supply system in accordance with the present invention can comprise a plurality of slant wells. With reference to FIGS. **5**A-**5**D, there are shown four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration **31**, a two-well array **32**, a three-well array **33**, and a four-well array **34**, in accordance with embodiments of the present invention. In each configuration, the slant wells all begin in the same vicinity of each other, i.e., they have common well head area **35**. As shown in FIGS. **5**A-**5**D, the well head area is located above the high tide line to maximize the undersea screened portion **36** of the slant wells.

[0066] With reference now to FIGS. **6**A and **6**B, there are shown a parallel slant well configuration **37** and a nonparallel slant well configuration **38**, in accordance with embodiments of the present invention. Each of these slant well configurations has a separate well head area for the slant wells in the configuration.

[0067] With reference now to FIG. **7**, there are shown a shallower-angle slant well **39** and a steeper-angle slant well **40**, the slant wells extending from a common wellhead area **41** but at different angles α_1 and α_2 below horizontal to produce water having different salinities, in accordance with an embodiment of the present invention. The freshwater-saltwater interface **44** is also shown to illustrate higher salinity production from the shallower-angle slant well **39** and lower salinity production from the steeper-angle slant well **40**.

[0068] Construction of a slant well for use in a feedwater supply system will now be described in more detail. In one embodiment, the initial construction of the slant well involves placing a telescoping plurality of casings beneath the land surface and ocean floor. With reference to FIG. **8**, there is shown an initial step in the construction of a telescoped slant well **45** having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention. The slant well comprises a 26-inch permanent casing **46** for the sanitary seal, a 24-inch permanent pump house casing **47**, a 22-inch temporary casing **48**, and a 20-inch temporary casing **49**.

[0069] With reference now to FIG. **9**, there is shown a second step in the construction of a telescoped slant well **50** having a single 12-inch-diameter well screen section **51**, in accordance with an embodiment of the present invention. An artificial filter pack **52** has been placed around the well screen section. The well screen section has been centered within a 20-inch temporary casing **54** using centering guides **53**.

[0070] Before operating a slant well in accordance with the present invention, the temporary casings surrounding the artificial filter pack and well screen section need to be withdrawn. FIGS. **10** and **11** illustrate the process of removing a 20-inch and 22-inch temporary casings from a telescoped slant well having a single well screen section. FIG. **10** shows a telescoped slant well **55** having a single well screen section **56** surrounded by an artificial filter pack **57** and centered using centering guides **58**. Dashed line **59** shows the extent of the 20-inch temporary casing prior to the start of the removal process. FIG. **11** shows a telescoped slant well **60** having a single well screen section **61** with both the 20-inch and 22-inch temporary casings removed. The top of the well screen **62** is cut off within the 24-inch pump house casing **63**, which is fitted with a seal **64** at the bottom of the pump house casing.

[0071] With reference now to FIG. **12**, there is shown a telescoped slant well **65** having dual screened intervals **66** and the temporary casings removed, in accordance with an embodiment of the present invention. Dashed line **67** shows the extent of the 20-inch temporary casing prior to the start of the removal process. The top of the well screen **68** is cut off within the 24-inch pump house casing, which is fitted with a seal **69** at the bottom of the pump house casing.

[0072] Before completing construction of a slant well in accordance with the present invention, the artificial filter pack needs to be placed and settled around the well screen sections. With reference to FIGS. **13**A and **13**B, there is shown a telescoped slant well **70** with an artificial filter pack **71** being placed through a system of multiple tremie pipes **72** in the annular space between the lower well screen **73** and the temporary casing **74**, in accordance with an embodiment of the present invention. The tremie pipes **72** are positioned using tremie pipe guides **75**, **76**, **77** and **78**.

[0073] FIGS. **14**A and **14**B further illustrate the process of placing and settling the artificial filter pack. These figures show a telescoped slant well **79** with an artificial filter pack **80** being placed and settled through a multi-step process. The filter pack is placed by pumping filter pack material **81** through the multiple tremie pipes **82** under pressure. Simultaneously, the temporary casing **83** surrounding the tremie pipes is removed and the filter pack **80** is settled using an in-screen packer assembly **84**. The in-screen packer assembly is configured to be slid inside a well screen. A water pipe extends from a water pump (not shown) through a hole in the in-screen packer. The water pump may be a standard water pump known to persons of ordinary skill in the art, with sufficient flow and pressure to cause water at the depth below the packer to flow outward through the well screen portion below the packer, thereby settling the filter pack in the vicinity of the packer. The in-screen packer assembly and tremie pipes are gradually withdrawn so that the artificial filter pack is placed and settled along the entire length of the well-screen portion of the slant well.

[0074] An engineered filter pack is designed to stabilize the subsea aquifer materials and, after proper development, prevent migration of fine sand and silt materials from the subsea aquifer into the well. With reference to FIG. **15**, there is shown an example chart of sieve opening versus percent of filter material passing the well screen slots for designing an engineered filter pack (line **85**) from site-specific samples of aquifer materials (line **86**) using the Terzaghi Migration Factor **87** as well as the filter pack sorting factor **88** and percentage of filter material passing the well screen slots **89**. This figure illustrates the principles behind the design of the artificial filter pack. A key purpose of the filter pack is to stabilize the aquifer. A key purpose of the well screen is to stabilize the filter pack.

[0075] To design the engineered filter pack, site-specific samples of aquifer materials are taken. It is next determined what sieve opening would pass 85 percent of the aquifer materials in the finest zone. In the example shown in FIG. **15**, it is determined that a sieve opening of approximately 0.6 millimeters would pass 85 percent of the finest aquifer materials within the screened interval of the well. The grain sizes of the filter pack are then chosen such that the 15-percent-passing filter pack size is no more than four times greater than the 85-percent-passing size of the finest aquifer materials within the screened section of the well. In the example of FIG. **15**, the 15-percent-passing filter pack size is 2.4 mm. The well screen slot openings are then sized such that 15 to 20 percent of the filter pack material will theoretically pass through the well screen slots. In the example shown in FIG. **15**, a well screen having approximately 0.094-inch (3/32-inch or 2.4-millimeter) slots is chosen. The uniformity coefficient (60 percent passing/10 percent passing) of the filter pack is typically about half the uniformity coefficient of the aquifer This ratio is known as the Sorting Factor.

[0076] As indicated above a slant well in accordance with the present invention can have multiple screened intervals and a dual-packer shroud assembly for providing greater flexibility in feedwater production. This flexibility can become important because of variations in the freshwater-saltwater interface due to national variations in the hydrologic cycle and a need to provide water of uniform salinity to a desalination plant. With reference to FIG. **16**, there is shown a multiple-screened, telescoped slant well **90** having multiple well screens, in accordance with an embodiment of the present invention. FIG. **16** illustrates how, without a means to vary the intake locations, a slant well can pump water with higher or lower salinity because of variations in the freshwater-saltwater interface due to natural variations in the hydrologic cycle. During wet hydrologic cycles, the freshwater-saltwater interface (line **91**) is farther from the shore due to the higher freshwater hydraulic head (line **92**). During dry hydrologic periods, the freshwater-saltwater interface (line **93**) is closer to the shore due to a lower freshwater hydraulic head (line **94**). The movement of the freshwater-saltwater interface is generally governed by the Ghyben-Herzberg principle, i.e., the depth to the interface (below sea level) is forty times the height of the freshwater head above sea level.

[0077] As will now be described, multiple screened intervals and a dual-packer shroud assembly can provide greater flexibility in feedwater production and lessen the effects of variations in the hydrologic cycle. With reference to FIG. **17**, there is shown a multi-screened, telescoped slant well **95** equipped with a submersible pump **96** fitted with a dual-packer shroud assembly and pumping from the lowermost screen **97** only (upper packer **98** inflated, lower packer **99** deflated), in accordance with an embodiment of the present invention. This configuration allows for greater production from the more saline portion **100** of the aquifer.

[0078] With reference now to FIG. **18**, there is shown a multi-screened, telescoped slant well **101** equipped with a submersible pump **102** fitted with a dual-packer shroud assembly and pumping from the uppermost screen **103** only (upper packer **104** deflated, lower packer **105** inflated), in accordance with an embodiment of the present invention. This configuration allows for greater production from the less saline portion **106** of the aquifer.

[0079] With reference now to FIG. **19**, there is shown a multi-screened, telescoped slant well **107** equipped with a submersible pump **108** fitted with a dual-packer shroud assembly and pumping from the well screen portion **109** between the dual packers (upper packer **110** and lower packer **111** inflated), in accordance with an embodiment of the present invention. This configuration allows for focused production from the portion of the aquifer proximate the well screen portion **109**.

[0080] The various configurations of the dual packer shroud assembly will now be described in greater detail with reference to FIGS. **20-23**. FIG. **20** shows a portion of a well having a submersible pump **112** fitted with a dual-packer shroud assembly **113**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **114** and a lower packer **115**. In FIG. **20**, the dual-packer shroud assembly is configured for maximum production (both upper packer **114** and lower packer **115** deflated). The upper packer is inflated and deflated using an upper packer air line **116**. The lower packer is inflated and deflated using a lower packer air line **117**. When both packers **114** and **115** are deflated, water enters the upper screen **118** from the aquifer and travels downward toward the pump in the annular space **119** between the upper screen and the pump discharge pipe. This upper water passes by the upper packer **114**, which is deflated, and enters the pump intake **120** through holes **121** in the shroud assembly. Water entering through the lower screen **122** from the aquifer travels upward toward the pump and passes by the lower packer **115**, which is deflated, and enters the pump intake through the holes **121** in the shroud assembly.

[0081] FIG. **21** shows a portion of a well having a submersible pump **123** fitted with a dual-packer shroud assembly **124**, in accordance with an embodiment of the present invention. The shourd assembly comprises two pneumatic packers: an upper packer **125** and a lower packer **126**. In FIG. **21**, the dual-packer shroud assembly is configured for production from below the lower packer (upper packer **125** inflated and lower packer **126** deflated). The upper packer is inflated and deflated using an upper packer air line **127**. The lower packer is inflated and deflated using a lower packer air line **128**. Water entering through the upper well screen is prevented from entering the pump intake by means of a permanent packer **129** and the inflated upper packer **125**. Water entering through the lower screen **130** from the aquifer travels upward toward the pump and passes by the lower packer **126**, which is deflated, and enters the pump intake through the holes **131** in the shroud assembly.

[0082] FIG. **22** shows a portion of a well having a submersible pump **132** fitted with a dual-packer shroud assembly **133**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **134** and a lower packer **135**. In FIG. **22**, the dual-packer shroud assembly is configured for production from above the upper packer (upper packer deflated **134** and lower packer inflated **135**). The upper packer is inflated and deflated using an upper packer air line **136** extending from an air pump (not shown) to the upper packer. The lower packer is inflated and deflated using a lower packer air line **137** extending from an air pump (not shown) to the upper packer. The air pump may be a standard air pump known to persons of ordinary skill in the art, sufficient to displace a volume of gas by physical or mechanical action to inflate and deflate the upper and lower packers. Water entering through the upper screen **138** from the aquifer travels downward toward the pump intake **139** and passes by the upper packer **134**, which is deflated, and enters the pump intake **139** through the holes **140** in the shroud assembly. Water entering through the lower well screen **141** is prevented from entering the pump intake by means of the inflated lower packer **135**. Guides **142** center the pump within the dual-packer shroud assembly.

[0083] FIG. **23** shows a portion of a well having a submersible pump **143** fitted with a dual-packer shroud assembly **144**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **145** and a lower packer **146**. In FIG. **23**, the dual-packer shroud assembly is configured for production from between the dual packers (both upper packer **145** and lower packer **146** inflated). The upper packer is inflated and deflated using an upper packer air line. The lower packer is inflated and deflated using a lower packer air line. Water enters the pump intake **147** from the screened section **148** between the packers. Water entering through the upper or lower well screens is prevented from entering the pump intake by means of the inflated upper packer **145** and lower packer **146**.

[0084] A slant well feedwater supply system in accordance with the present invention can be constructed near and/or beneath any saline water source, but more preferably is constructed where a river delta deposit meets the ocean, where a major drainage (such as a creek, stream or river) discharges into the ocean, or where an aquifer system under a land surface extends offshore. An initial field investigation is preferably conducted to determine the potential of a site to yield water for a desalination plant. This exploratory work may involve drilling boreholes and test wells to an appropriate depth both onshore and offshore to properly characterize the subsurface aquifer system, which may typically be sand and gravels but may also include secondary porosity features in consolidated rock aquifers (e.g. carbonate aquifers). In one embodiment, the boreholes and test wells are drilled 50 to 200 feet deep. The lithologic characterization of the aquifers may also indicate the quality of the water that might be supplied for a well drilled at that site (e.g., in terms of total dissolved solids (TDS), chlorides and other chemical constituents of concern in a desalination feedwater supply and how those constituents vary with depth).

[0085] In one embodiment, the slant well feedwater supply system extends at approximately a 23-degree angle below horizontal to a total length of approximately 350 feet and is capable of providing 2,000-gpm feedwater supply having an average silt density index of approximately 0.58 and an NTU between approximately 0.15 and 0.33. Of the total length, the first approximately 130 feet can comprise a blank casing, followed by approximately 220 feet of a well screen. The well screen can comprise a plurality of Roscoe Moss Full-Flo louver well screens having 3/32-inch slots, the plurality welded together end-to-end to form the complete well screen. The well screen and blank casing can have an inner diameter of 12⅛ inches and a wall thickness of 5/16-inches. In one embodiment, the well screen and blank casing comprise 316L stainless steel. The artificial filter pack can comprise Colorado Silica ¼×16 packed approximately 5 inches thick around the well screen. In one particular embodiment, the full scale system comprises a plurality of seven 1,000-foot slant wells, with each well supplying a feedwater supply of approximately 3,000 gpm for a total supply of approximately 30 mgd.

[0086] The foregoing detailed description of the present invention is provided for purposes of illustration, and it is not intended to be exhaustive or to limit the invention to the particular embodiments disclosed. The embodiments may provide different capabilities and benefits, depending on the configuration used to implement the key features of the invention. Accordingly, the scope of the invention is defined only by the following claims.

What is claimed is:

1. A telescoping slant well system for returning water to a subsurface aquifer system, the feedwater supply system comprising:

a primary well screen for injecting water into the aquifer system, the primary well screen oriented along an axis angled less than ninety degrees below horizontal and having a substantially uniform cross-sectional area;

a filter pack substantially surrounding and adjacent to the primary well screen;

a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and

a submersible pump contained within the pump house casing for pumping water to be injected through the primary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

* * * * *

GEOSCIENCE

March 27, 2013

VIA E-MAIL AND CERTIFIED U.S. MAIL

Mr. Paul Findlay
RBF Consulting
9755 Clairemont Mesa Blvd, Suite 100
San Diego, CA 92124

Re: Slant Well Desalination Feedwater Supply System and Method for Constructing the Same - Notice of U.S. Patent No. 8,056,629 and U.S. Patent Publication No. 2012/0292012

Dear Paul:

We appreciate your confidence and thank you for selecting us to work with you on the Monterey Peninsula Water Supply Project.

As you know, GEOSCIENCE Support Services, Inc. ("GSSI") owns several U.S. patents and published patent applications. Per our prior conversation, I write to specifically bring to your attention GSSI's recently issued U.S. Patent No. 8,056,629, titled "Slant Well Desalination Feedwater Supply System and Method for Constructing Same" and GSSI's recently published U.S. Patent Application Publication No. 2012/0292012, titled "Desalination Subsurface Feedwater Supply and Brine Disposal." This patent and patent application publication are pertinent to the test slant and observation wells that GSSI will be designing for you. Copies of this patent and patent application publication are enclosed for your reference.

Please note that all intellectual property of GSSI, including without limitation the patent and patent application publication mentioned above, will at all times remain the sole property of GSSI. No assignment or license of any inventions, patents, copyrights, trademarks, trade secrets, or other intellectual property rights, or applications for same, is granted or conveyed to you. If you have any questions, please do not hesitate to contact me.

Sincerely

Meridee E. Williams

SMRH:408073253.1
Encl.: U.S. Patent No. 8,056,629 and U.S. Patent Application Publication No. 2012/0292012

cc: Mr. Richard Svindland/ Cal American Water

GEOSCIENCE SUPPORT SERVICES INCORPORATED
Ground Water Resources Development
P.O. Box 220, Claremont, CA 91711
FAX 909-451-6638
909-451-6650

GEOSCIENCE

May 13, 2011

RMC WATER AND ENVIRONMENT
2290 North First Street, Suite 212
San Jose, CA 95131
Attn: Joe Green-Heffern

Re: RMC Project: 0139-011 – Section 9.1 – Project Records - Patents and Copyrights
Title of Subcontract: REGIONAL DESALINATION PROJECT PM SUBCONTRACT AGREEMENT FOR SERVICES

GEOSCIENCE Support Services, Inc. US Patent Application No. 12/478,886 – Slant Well Desalination Feedwater Supply System and Method for Constructing Same

Dear Joe:

As per Section 9.1 – Project Records of the subcontract dated May 2011, please consider this written notification that, in performing the work for the above-referenced contract, GEOSCIENCE Support Services, Inc. anticipates using the information and technologies contained in US Patent Application No. 12/478,886 – Slant Well Desalination Feedwater Supply System and Method for Constructing Same.

This patent application has been filed by GEOSCIENCE Support Services, Inc. And, as per the subcontract, by informing RMC WATER AND ENVIRONMENT in writing of the intent to use this proprietary/corporate patent information and technology, GEOSCIENCE Support Services, Inc. maintains that it is the sole owner of such technology and patent application, and does not transfer or assign any rights of ownership to RMC WATER AND ENVIRONMENT or the Marina Coast Water District, the Monterey County Water Agency, California American Water, or any other WPA Party who may join in the future. Please consider this written notification part of the written agreement between RMC WATER AND ENVIRONMENT and GEOSCIENCE Support Services, Inc.

Respectfully submitted,

Dennis E. Williams, Ph.D.
President
cc: Tony Valdivia

US008479815B2

(12) **United States Patent**
Williams

(10) **Patent No.: US 8,479,815 B2**
(45) **Date of Patent: *Jul. 9, 2013**

(54) **DESALINATION SUBSURFACE FEEDWATER SUPPLY AND BRINE DISPOSAL**

(75) Inventor: **Dennis E. Williams**, Altadena, CA (US)

(73) Assignee: **GEOSCIENCE Support Services, Inc.**, La Verne, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/295,990**

(22) Filed: **Nov. 14, 2011**

(65) **Prior Publication Data**

US 2012/0292012 A1 Nov. 22, 2012

Related U.S. Application Data

(63) Continuation-in-part of application No. 12/748,886, filed on Mar. 29, 2010, now Pat. No. 8,056,629.

(60) Provisional application No. 61/293,134, filed on Jan. 7, 2010.

(51) **Int. Cl.**

E21B 43/10	(2006.01)
E21B 43/04	(2006.01)
E02B 11/00	(2006.01)

(52) **U.S. Cl.**

USPC **166/278**; 166/369; 166/51; 166/54.1; 166/105.1; 405/43; 405/47; 405/48; 405/50

(58) **Field of Classification Search**

USPC 166/278, 369, 374, 51, 54.1, 74, 166/105.1; 405/43, 47, 48, 50

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,014,387	A *	3/1977	Fink	166/369
4,199,272	A *	4/1980	Lacey	405/36
4,296,810	A *	10/1981	Price	166/265
4,372,389	A *	2/1983	Hamrick et al.	166/369
4,407,360	A *	10/1983	Hamrick	166/68
4,714,117	A *	12/1987	Dech	166/380
4,779,682	A *	10/1988	Pelzer	166/370
5,133,411	A *	7/1992	Gadelle et al.	166/370
5,209,605	A *	5/1993	Cherrington	405/184
5,343,965	A *	9/1994	Talley et al.	175/62
5,520,247	A *	5/1996	Gmelig Meyling et al.	166/245
5,771,976	A *	6/1998	Talley	166/370

(Continued)

FOREIGN PATENT DOCUMENTS

WO 01/88332 11/2001

OTHER PUBLICATIONS

Bill Brinker, P.E., Vermillion Angle Well for Lewis & Clark Rural Water System, Apr. 7, 2004.

(Continued)

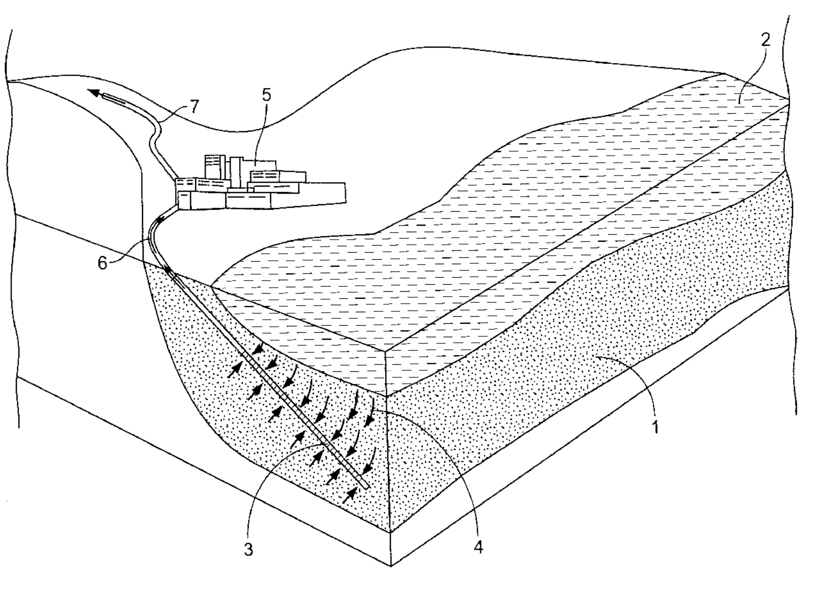
Primary Examiner — Jennifer H Gay

(74) *Attorney, Agent, or Firm* — Sheppard, Mullin, Richter & Hampton LLP

(57) **ABSTRACT**

A system for supplying water to a desalination plant from a subsurface feedwater supply using one or more slant or horizontally directionally drilled ("HDD") wells, and for concentrate disposal (e.g., injection of brine). A method for constructing a slant or HDD well feedwater supply system for supplying water from a subsurface feedwater supply or to inject concentrate into a subsea aquifer.

52 Claims, 26 Drawing Sheets



U.S. PATENT DOCUMENTS

6,073,659	A *	6/2000	Lange	138/177
6,422,318	B1 *	7/2002	Rider	166/380
6,581,683	B2 *	6/2003	Ohanesian	166/236
6,581,688	B2 *	6/2003	Voll et al.	166/278
6,811,353	B2 *	11/2004	Madison	405/41
7,000,711	B2 *	2/2006	Miller et al.	175/65
7,096,959	B2 *	8/2006	McDonald	166/369
7,118,307	B2	10/2006	Stoecker et al.	
7,207,381	B2 *	4/2007	Sharp	166/54.1
7,322,422	B2 *	1/2008	Patel	166/387
7,654,343	B2 *	2/2010	Snow	175/61
7,699,557	B2 *	4/2010	Shaw et al.	404/2
8,056,629	B2 *	11/2011	Williams	166/278
2001/0047865	A1 *	12/2001	Voll et al.	166/250.14
2002/0033266	A1 *	3/2002	Hester et al.	166/369
2002/0189809	A1 *	12/2002	Nguyen et al.	166/278
2003/0180094	A1 *	9/2003	Madison	405/36
2005/0039907	A1 *	2/2005	Madison	166/67
2005/0173124	A1 *	8/2005	McDonald	166/369
2005/0173156	A1 *	8/2005	Miller et al.	175/62
2006/0127184	A1 *	6/2006	Madison	405/41
2006/0260795	A1 *	11/2006	Rescia	166/51
2008/0142227	A1 *	6/2008	Yeh et al.	166/369
2009/0008092	A1 *	1/2009	Haeberle et al.	166/278
2009/0178801	A1 *	7/2009	Nguyen et al.	166/249
2009/0241685	A1 *	10/2009	Charette	73/861.07
2011/0162850	A1 *	7/2011	Williams	166/369
2012/0292012	A1 *	11/2012	Williams	166/105

OTHER PUBLICATIONS

Gary Smith, A New Angle on Well Construction, Approximately 2005.

Dennis E. Williams, The Use of Wells to Provide Water for Seawater Desalination Systems, 15th Annual GRA Meeting and Conference, San Diego, California, Sep. 22, 2006.

Dennis E. Williams, Use of Low Angled Wells for Desalination Feedwater Systems, ASCE Hydrology & Hydraulics Committee Meeting Presentation, Aug. 28, 2007.

Dennis E. Williams, Radial Wells, The Encyclopedia of Water, John Wiley and Sons, 2005.

Mr. Richard Bell, P.E. and Dennis Williams, Ph.D.—Overview of the Dana Point Ocean Desalination Project, May 14, 2008.

Dennis E. Williams, Slant Well Installed and Tested in Dana Point, California, Horizontal News, Summer 2007, vol. 10, No. 1 National Ground Water Association.

Dennis E. Williams, Results of Drilling, Construction, Development and Testing of Dana Point Ocean Desalination Project Test Slant Well, Horizontal News, Summer 2007, vol. 10, No. 1, National Ground Water Association.

California; SoCal SWRO Study Presented, Water Desalination Report, May 18, 2009, vol. 45, No. 19, Media Analytics.

South Coast Coastal Ocean Desalination Project Update, Laguna County Water District—Waves, Jan./Feb. 2009, vol. 5, Issue 1.

Municipal Water District of Orange County, Dana Point Ocean Desalination Project, Project Overview, Apr. 2007.

* cited by examiner

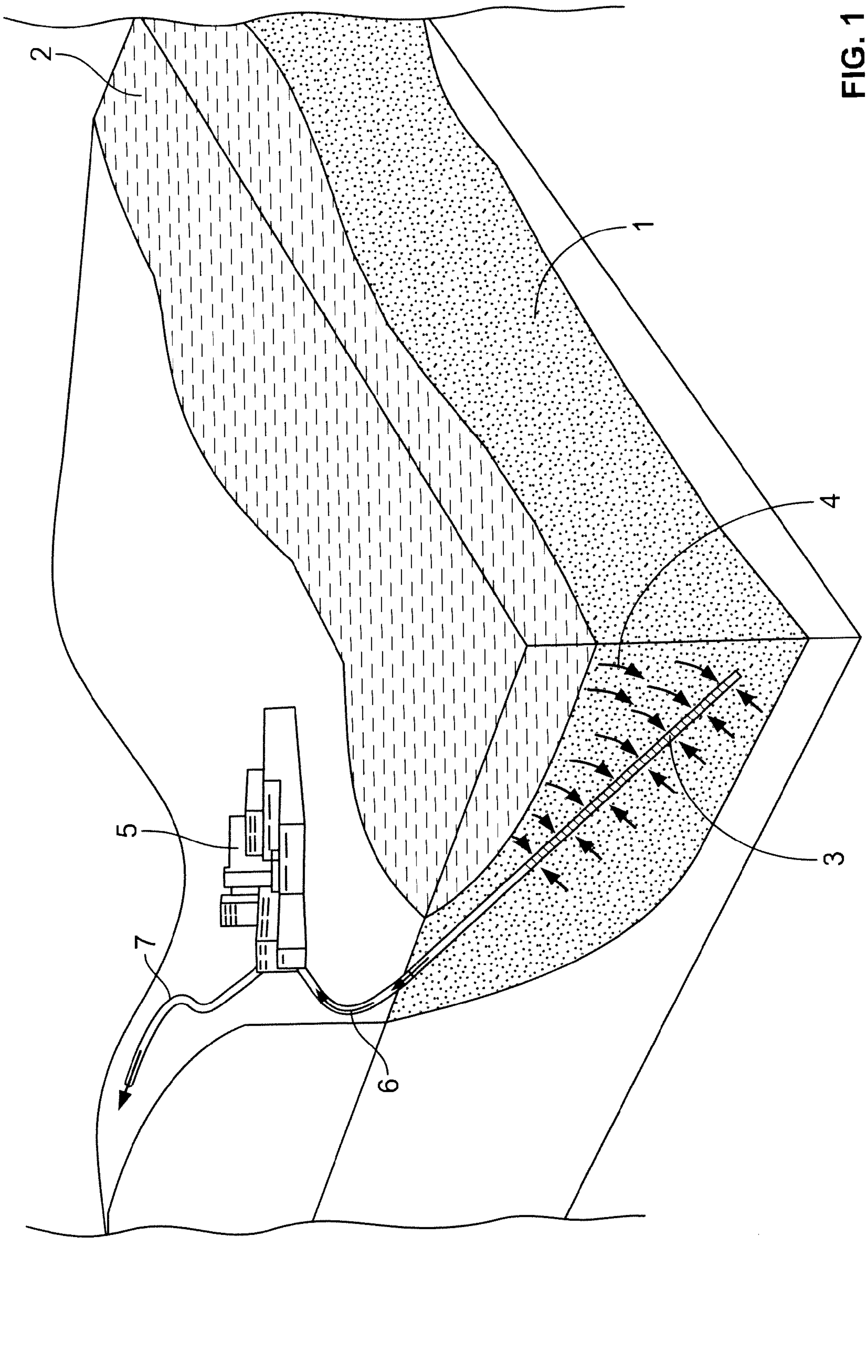


FIG. 1

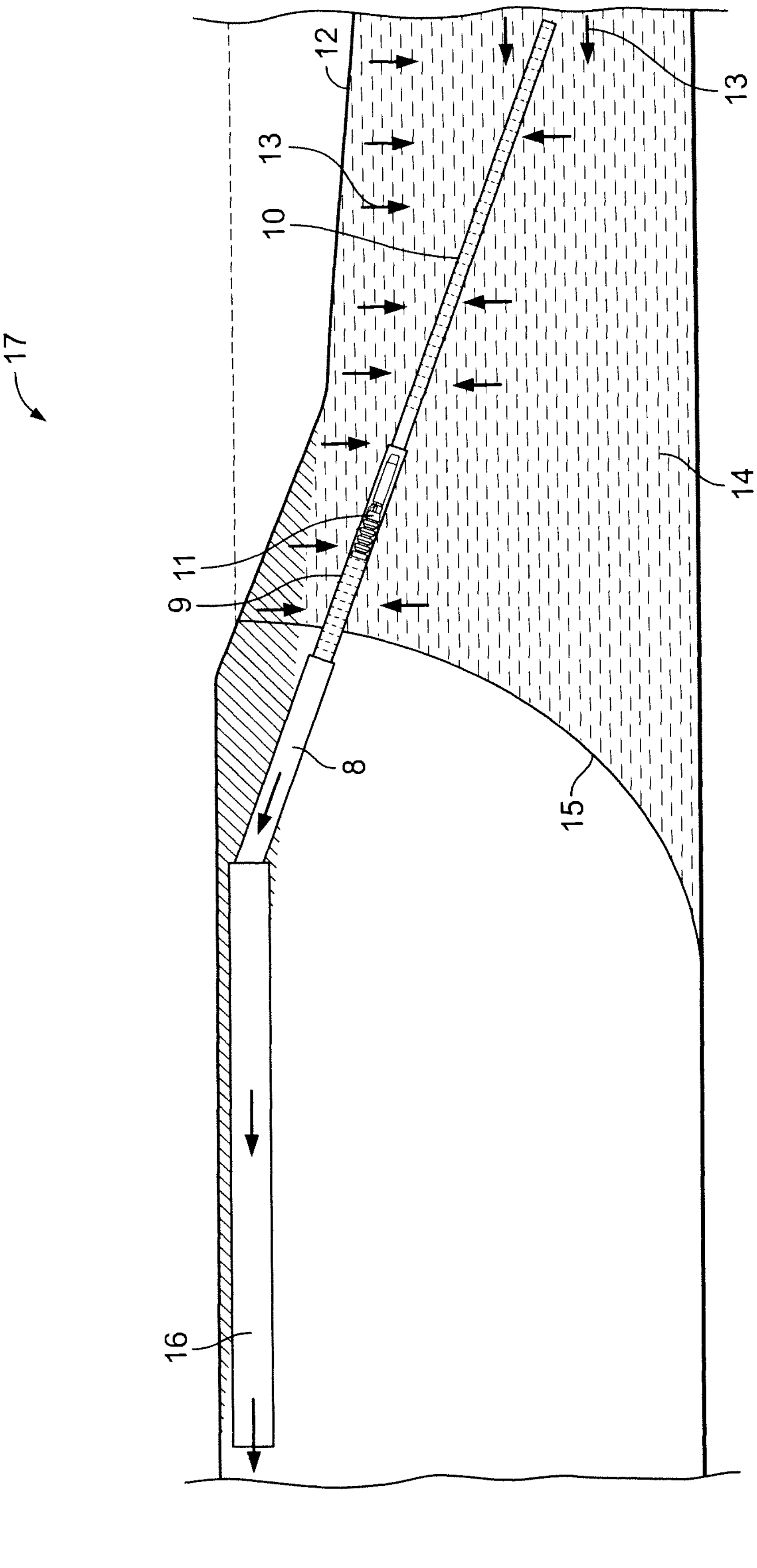


FIG. 2

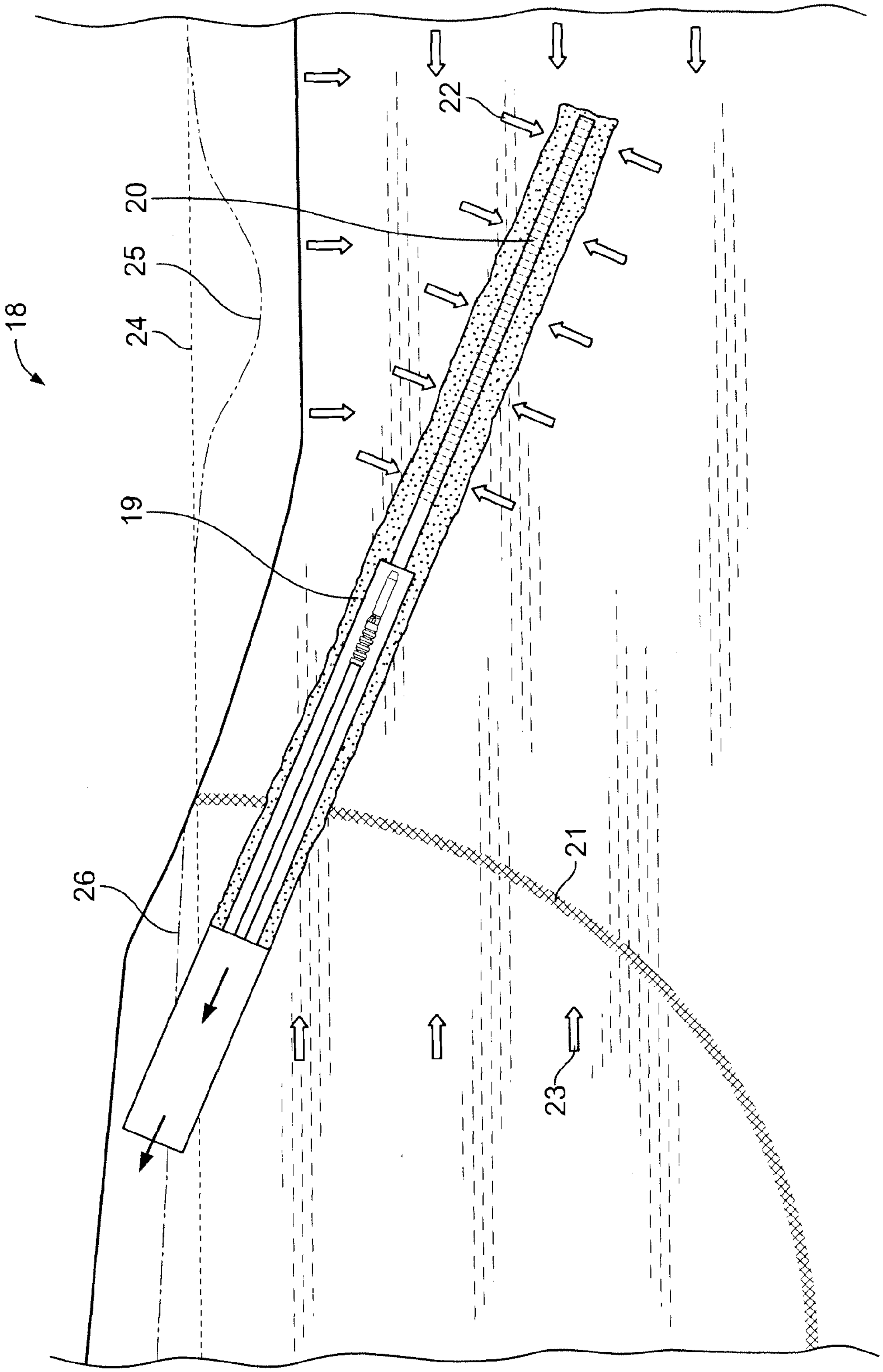


FIG. 3

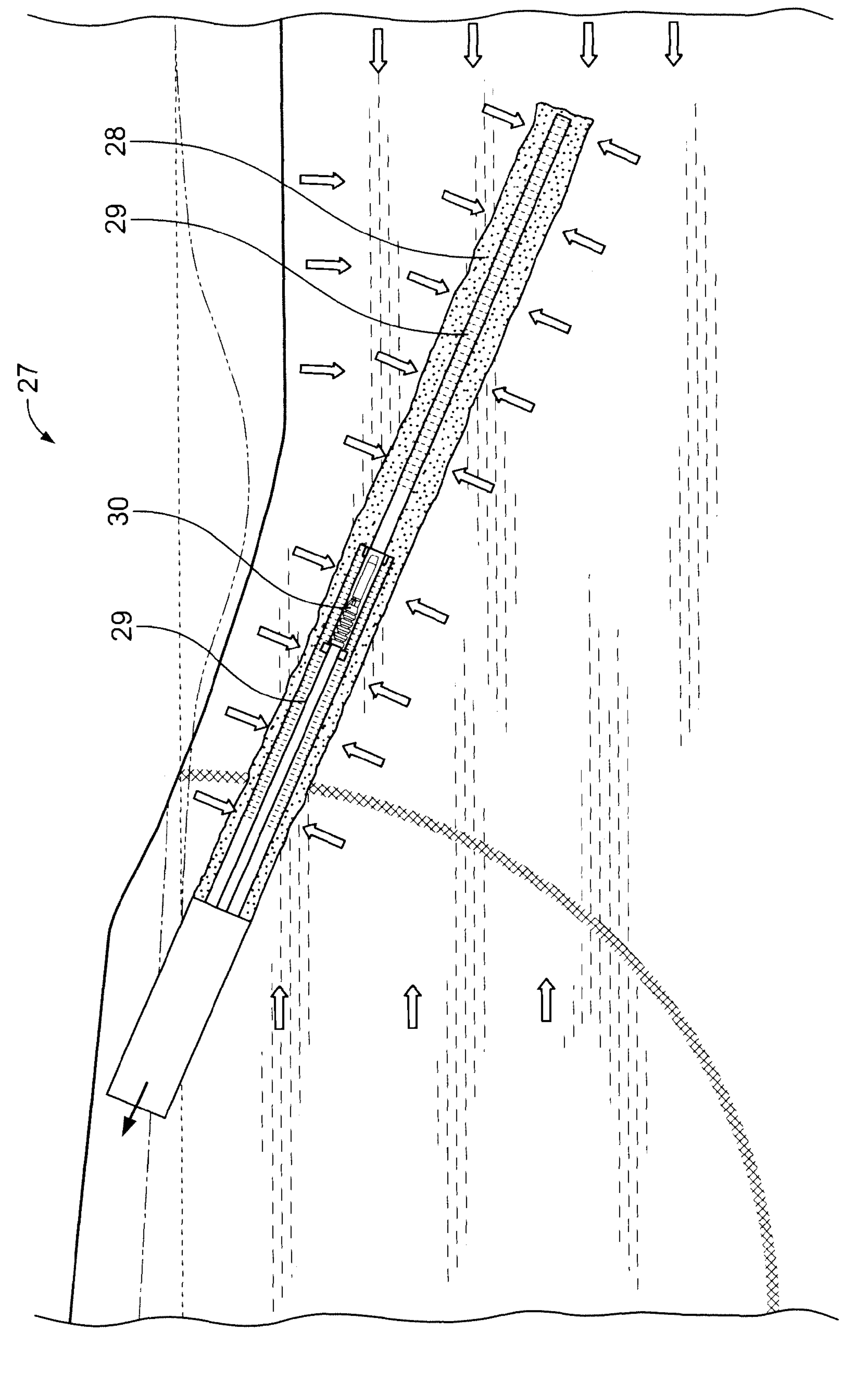


FIG. 4

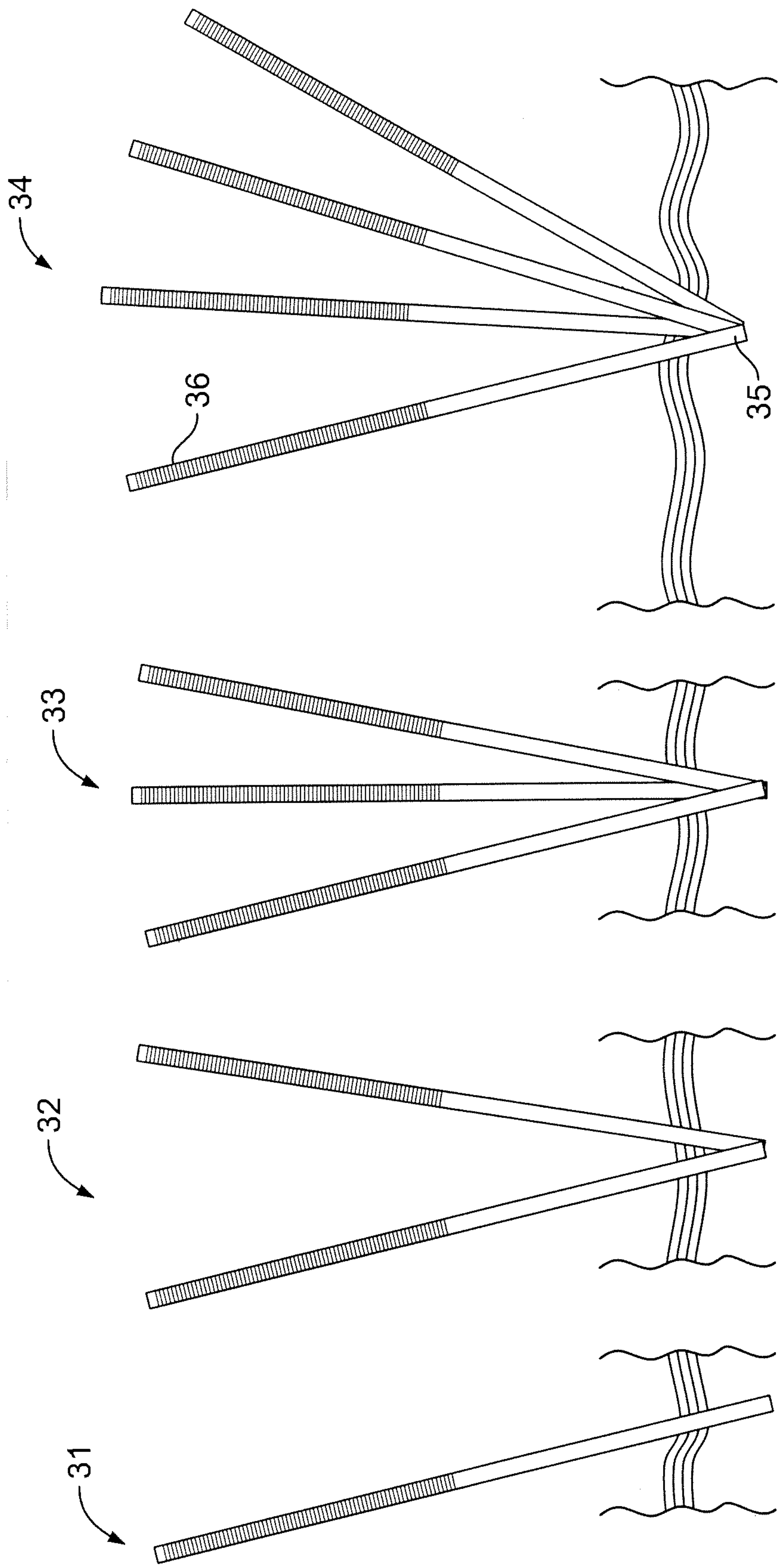


FIG. 5D

FIG. 5C

FIG. 5B

FIG. 5A

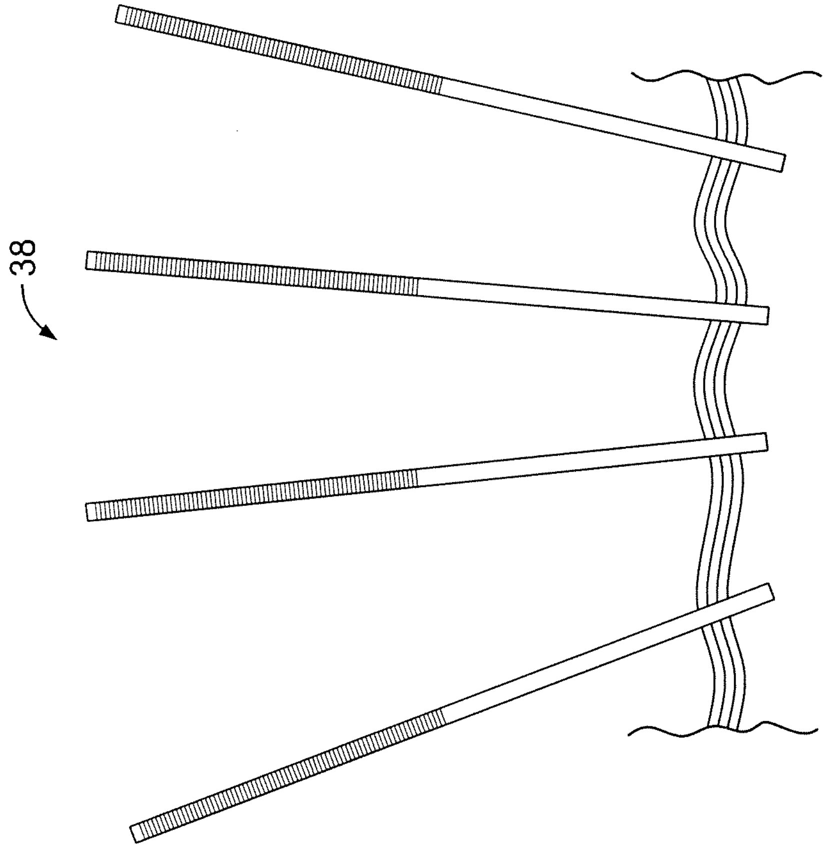


FIG. 6B

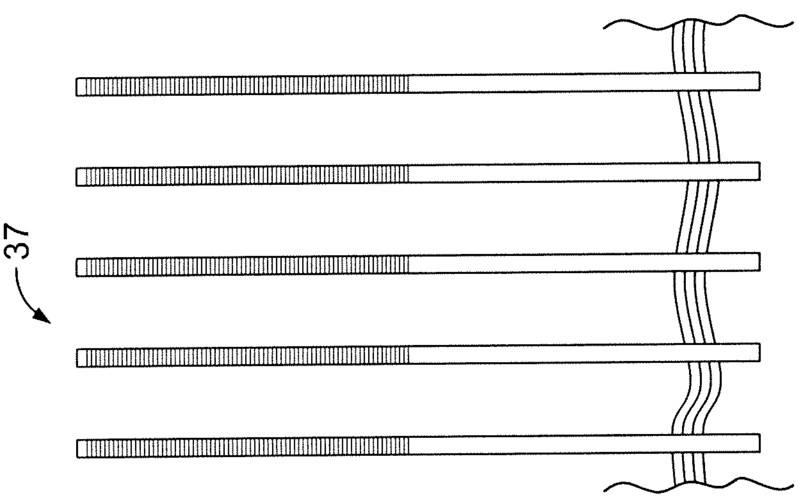


FIG. 6A

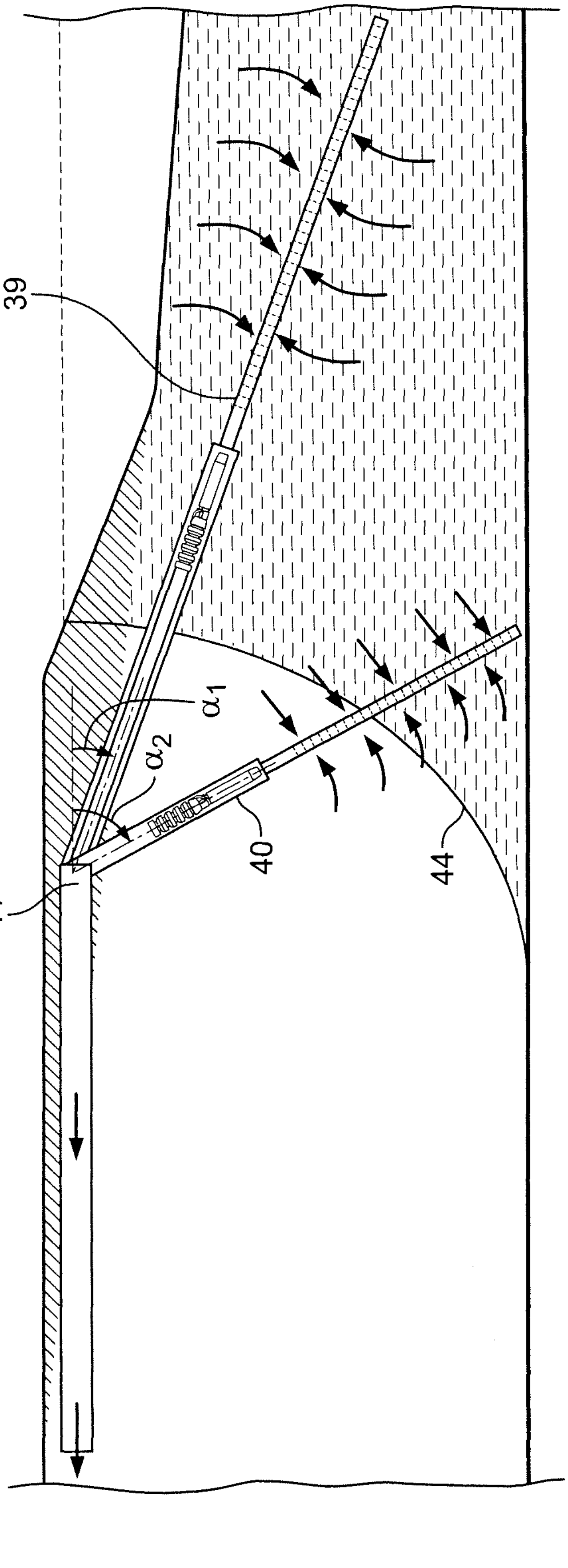


FIG. 7

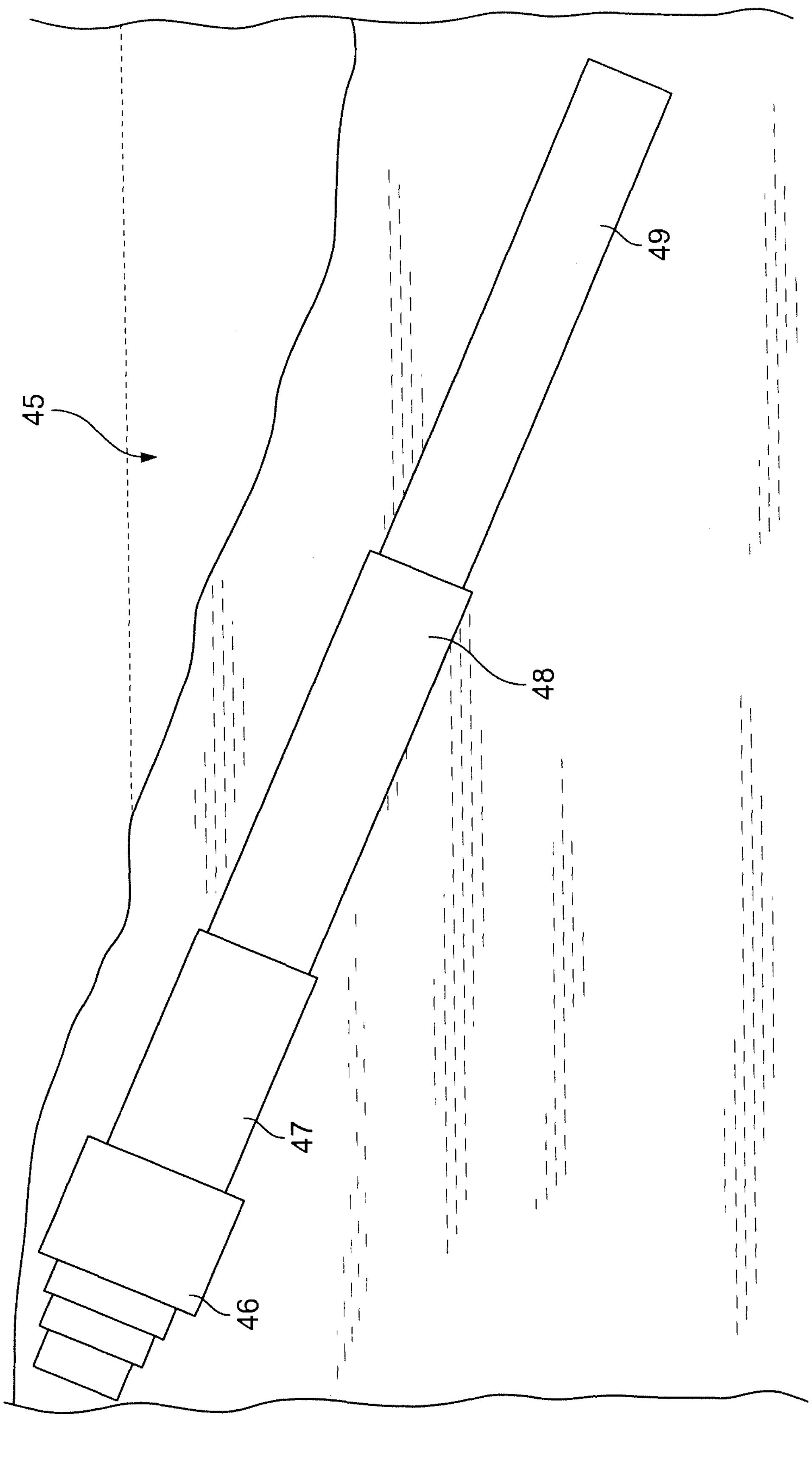


FIG. 8

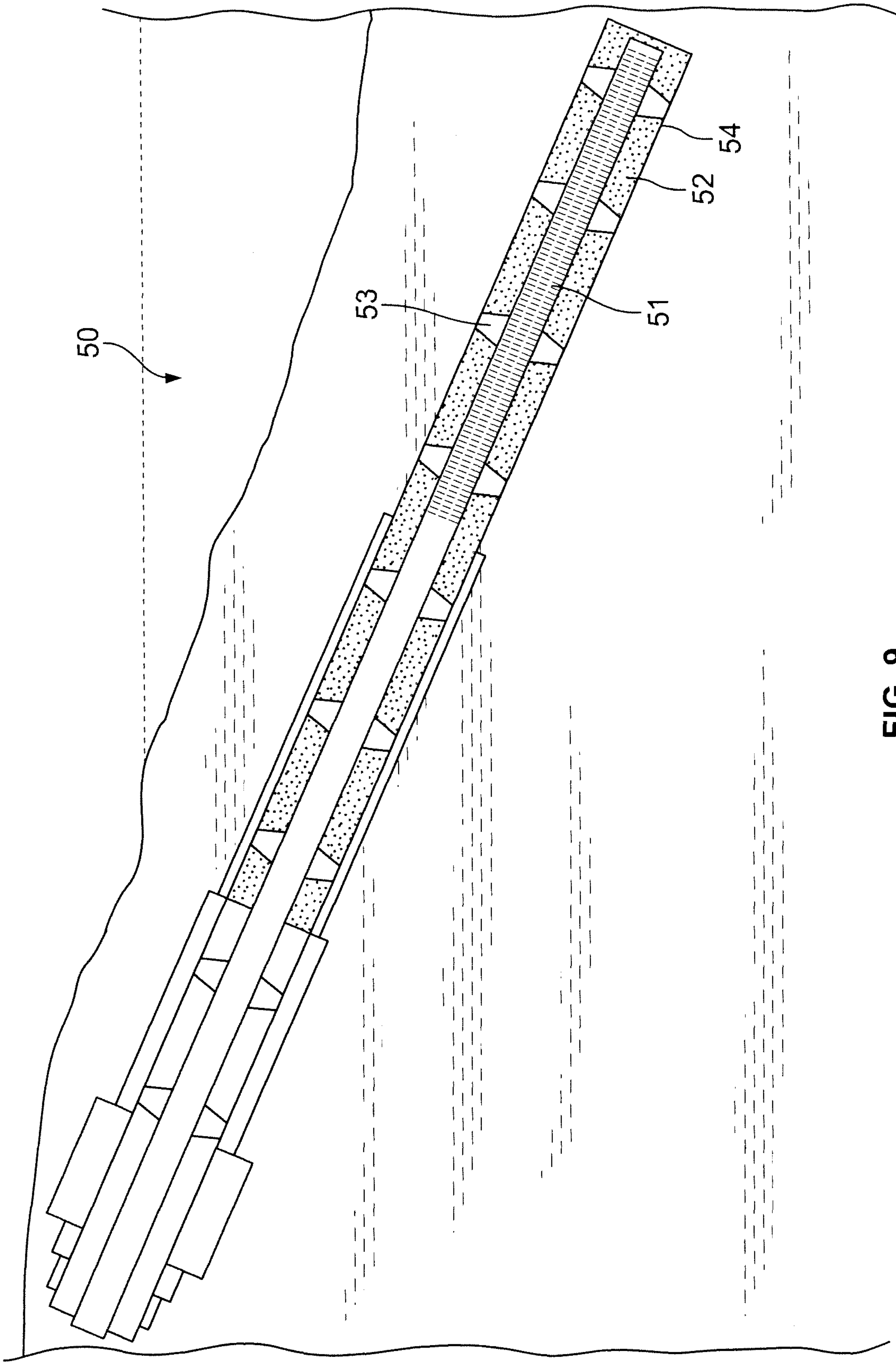


FIG. 9

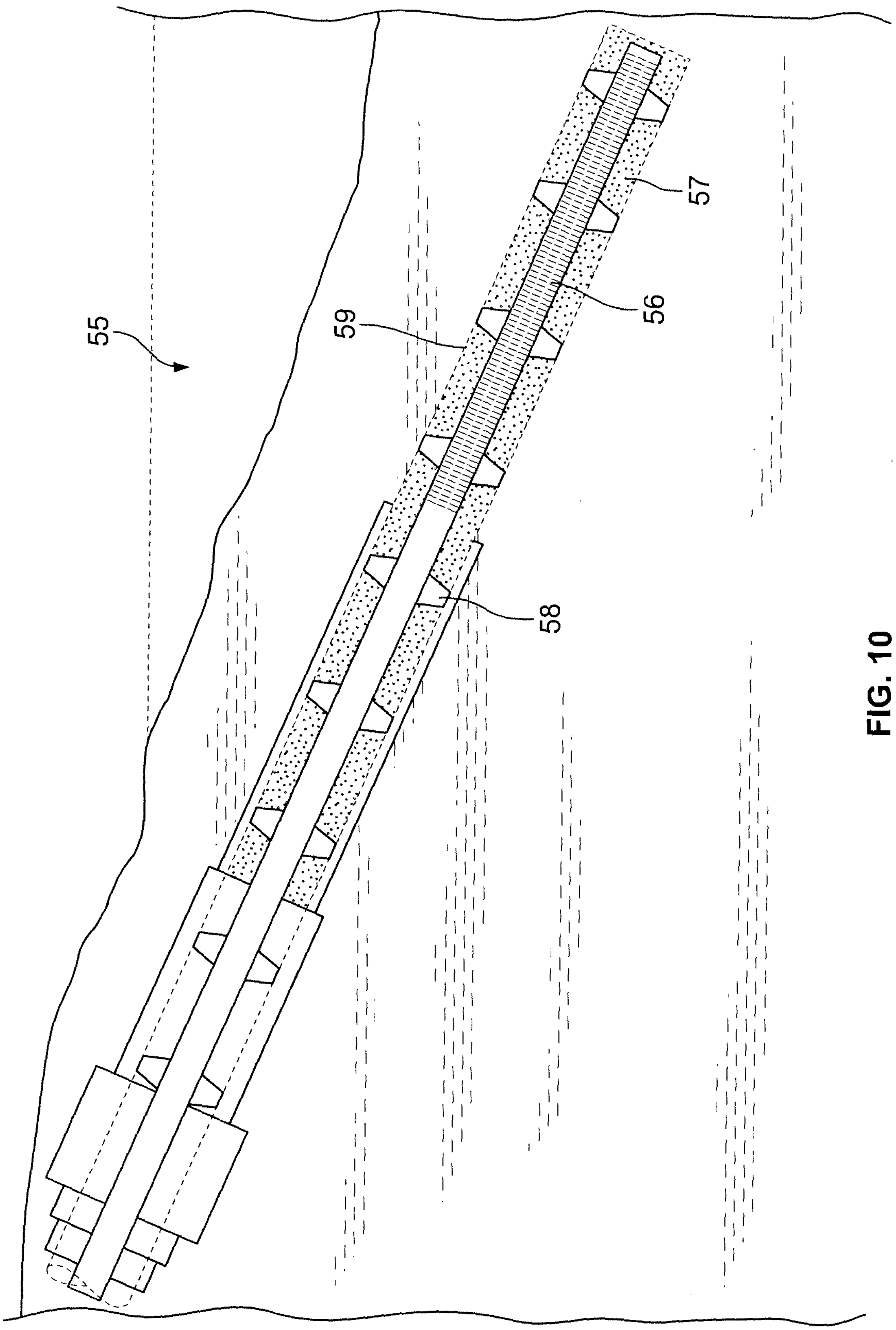


FIG. 10

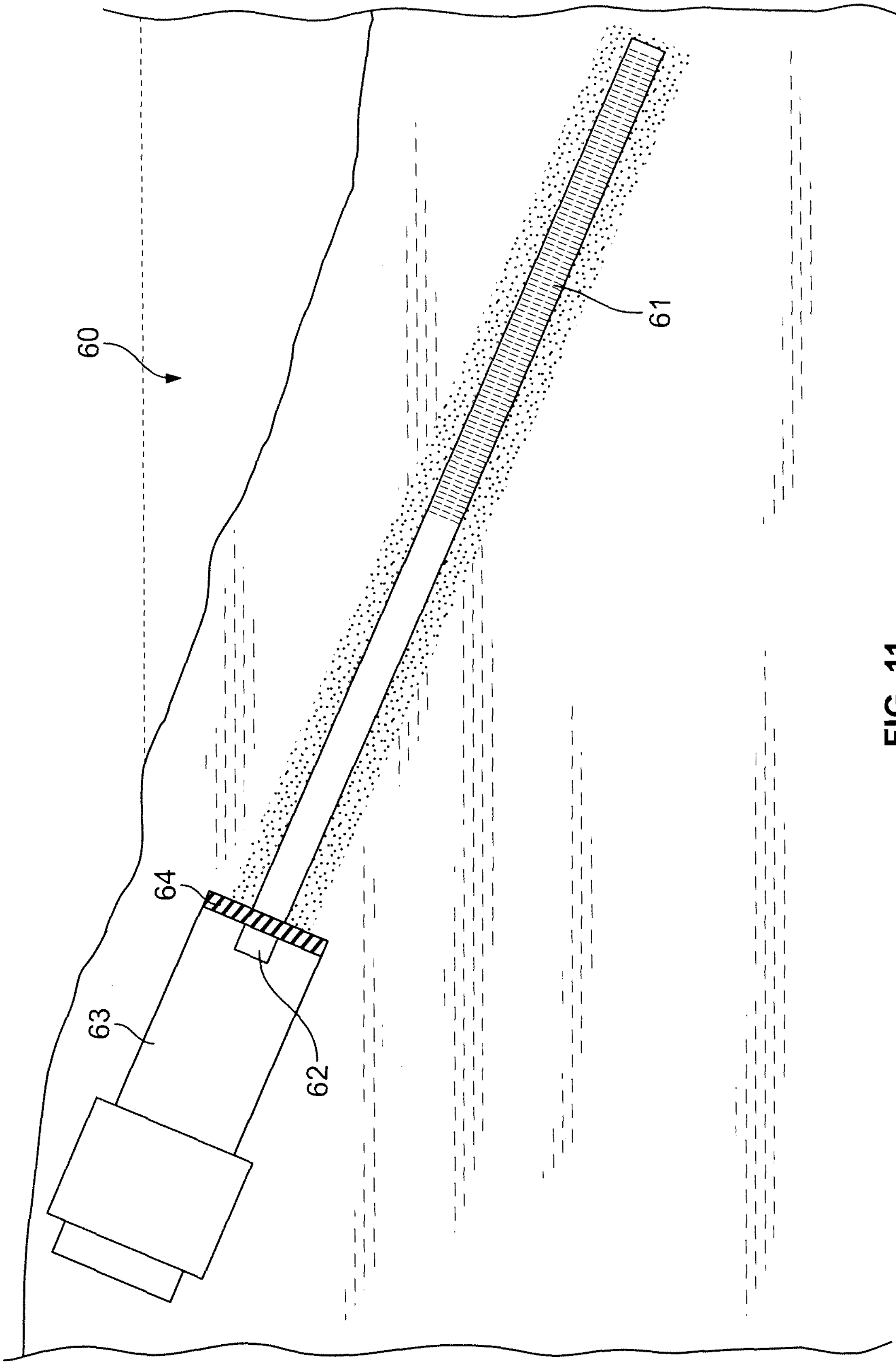


FIG. 11

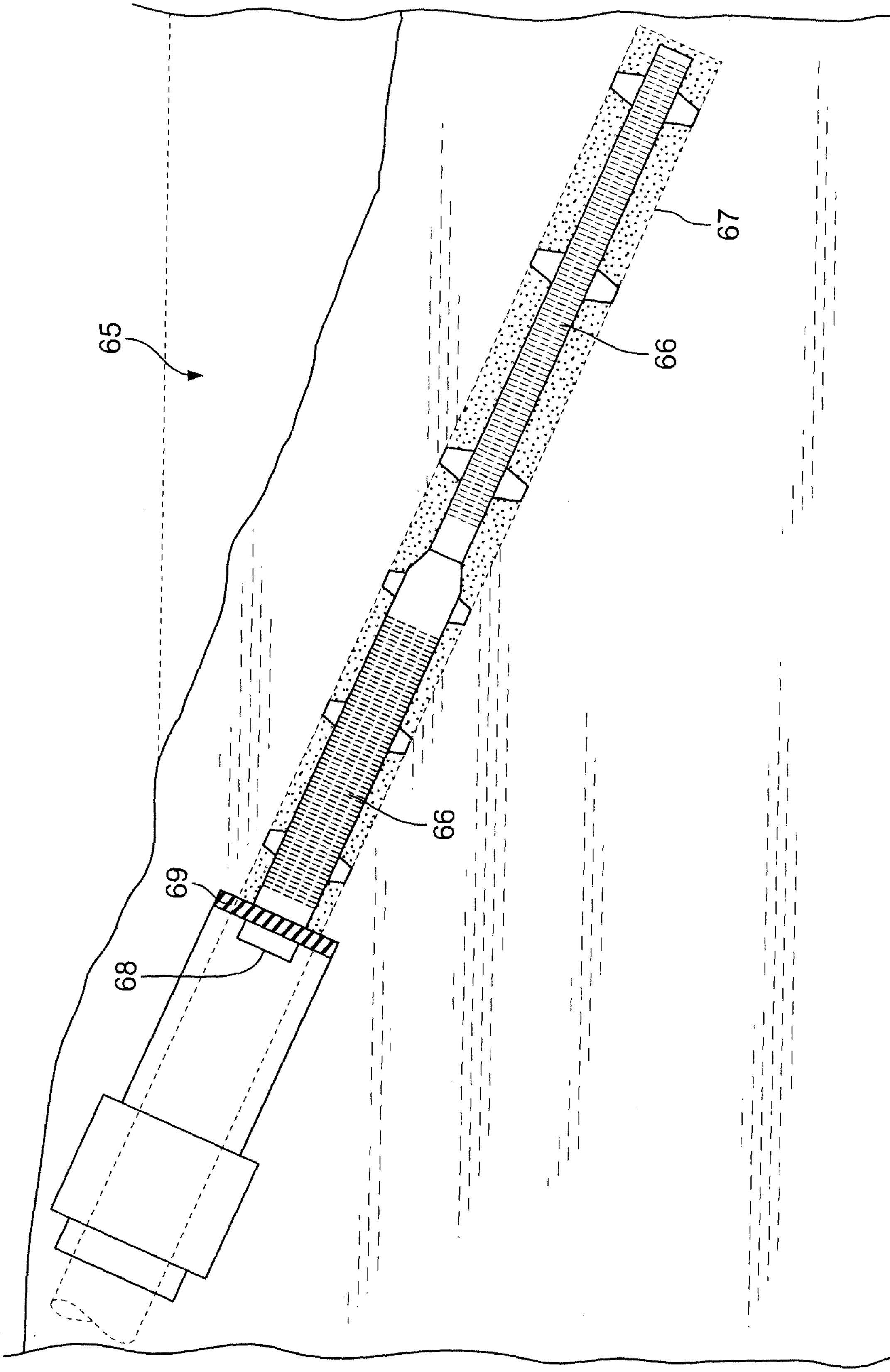


FIG. 12

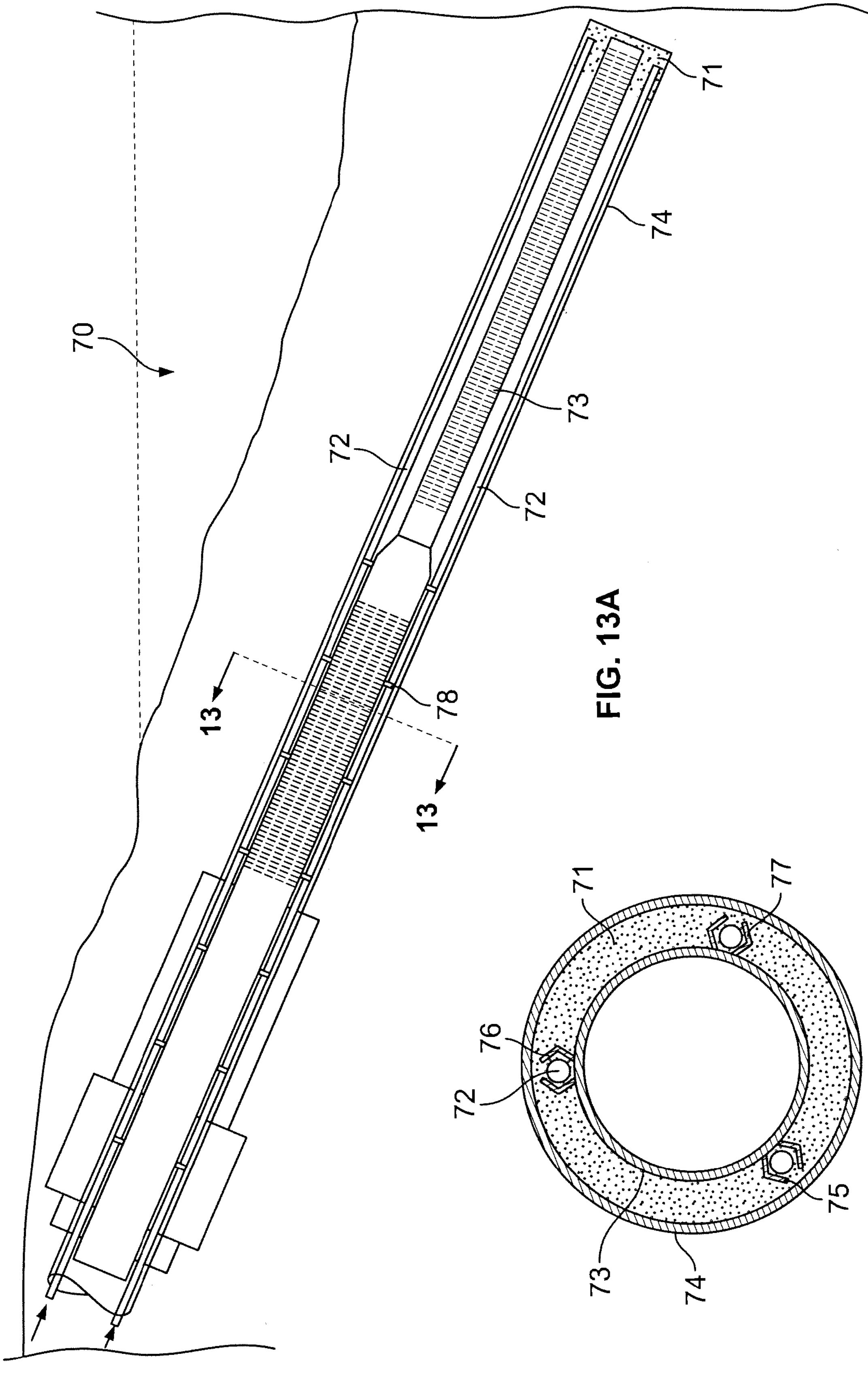


FIG. 13A

FIG. 13B

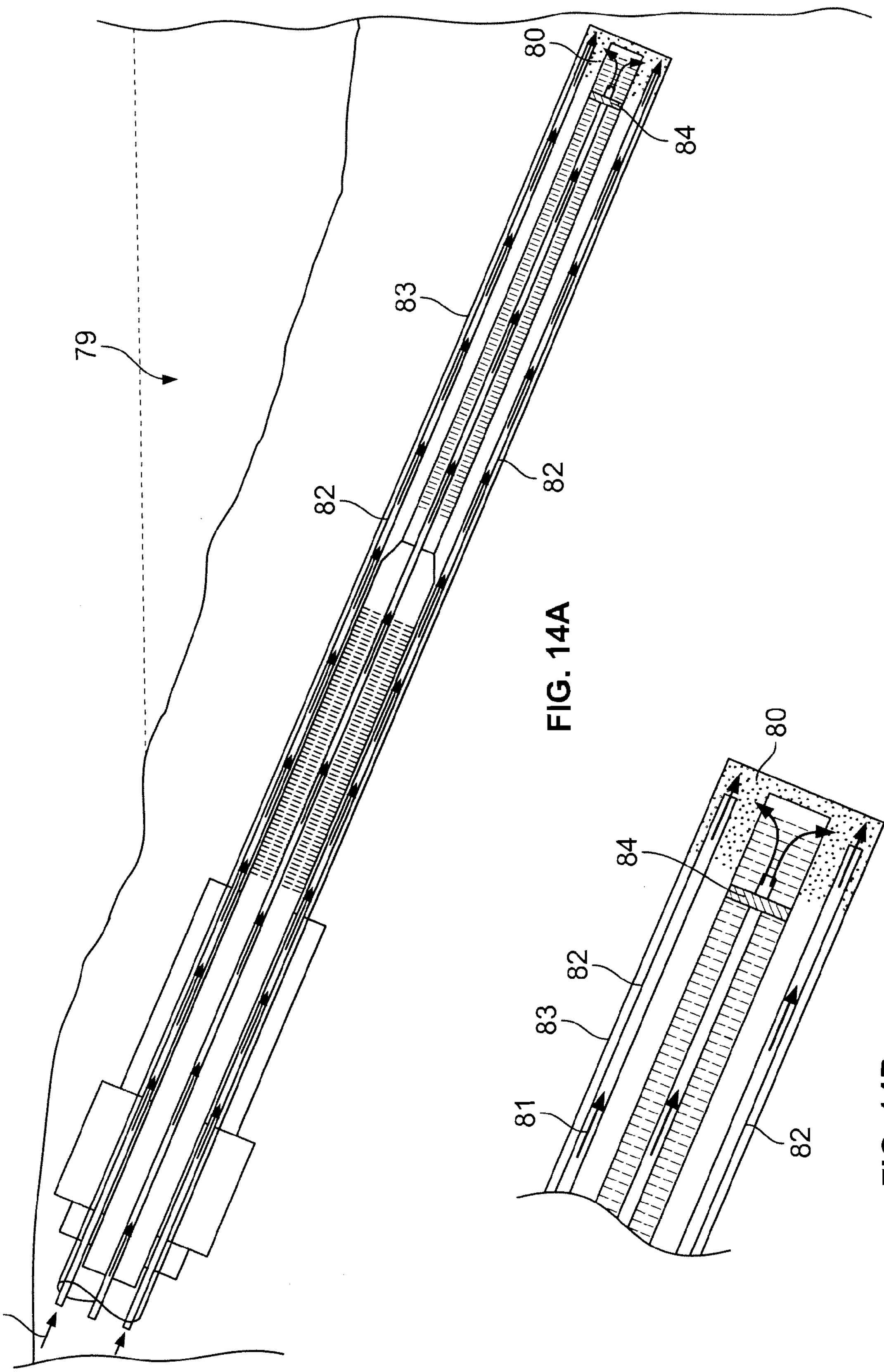


FIG. 14A

FIG. 14B

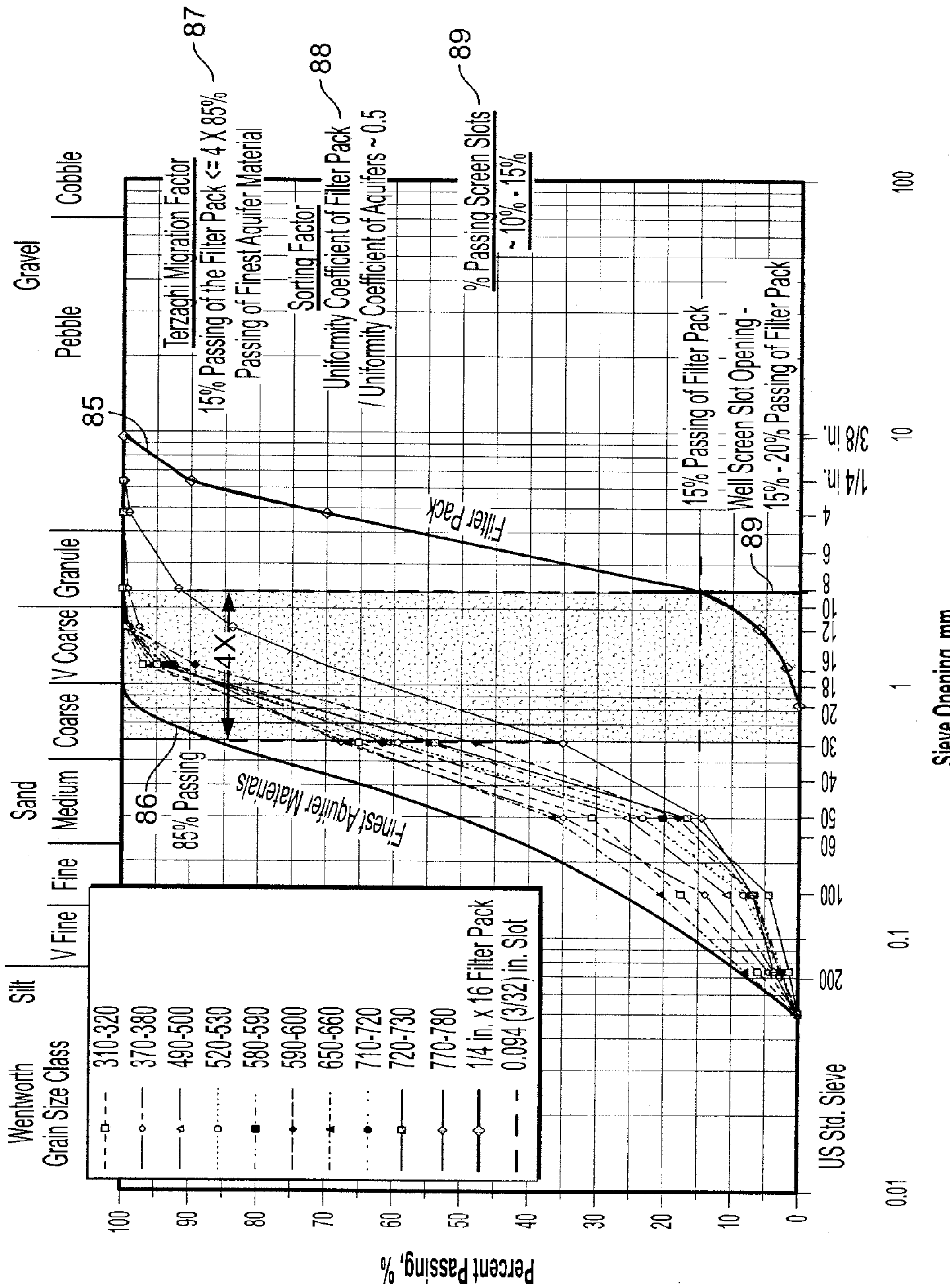

Wentworth Grain Size Class
Silt
V Fine
Fine
Sand
Medium
Coarse
V Coarse
Granule
Pebble
Gravel
Cobble
310-320
370-380
490-500
520-530
580-590
590-600
650-660
710-720
720-730
770-780
1/4 in. x 16 Filter Pack
0.094 (3/32) in. Slot
Terzaghi Migration Factor
15% Passing of the Filter Pack <= 4 X 85%
Passing of Finest Aquifer Material
Sorting Factor
Uniformity Coefficient of Filter Pack
/ Uniformity Coefficient of Aquifers ~ 0.5
% Passing Screen Slots
~ 10% - 15%
87
88
89
85
86
85% Passing
4X
Finest Aquifer Materials
Filter Pack
15% Passing of Filter Pack
Well Screen Slot Opening -
15% - 20% Passing of Filter Pack
Percent Passing, %
Sieve Opening, mm
US Std. Sieve
0.01
0.1
1
10
100
3/8 in.
1/4 in.

FIG. 15

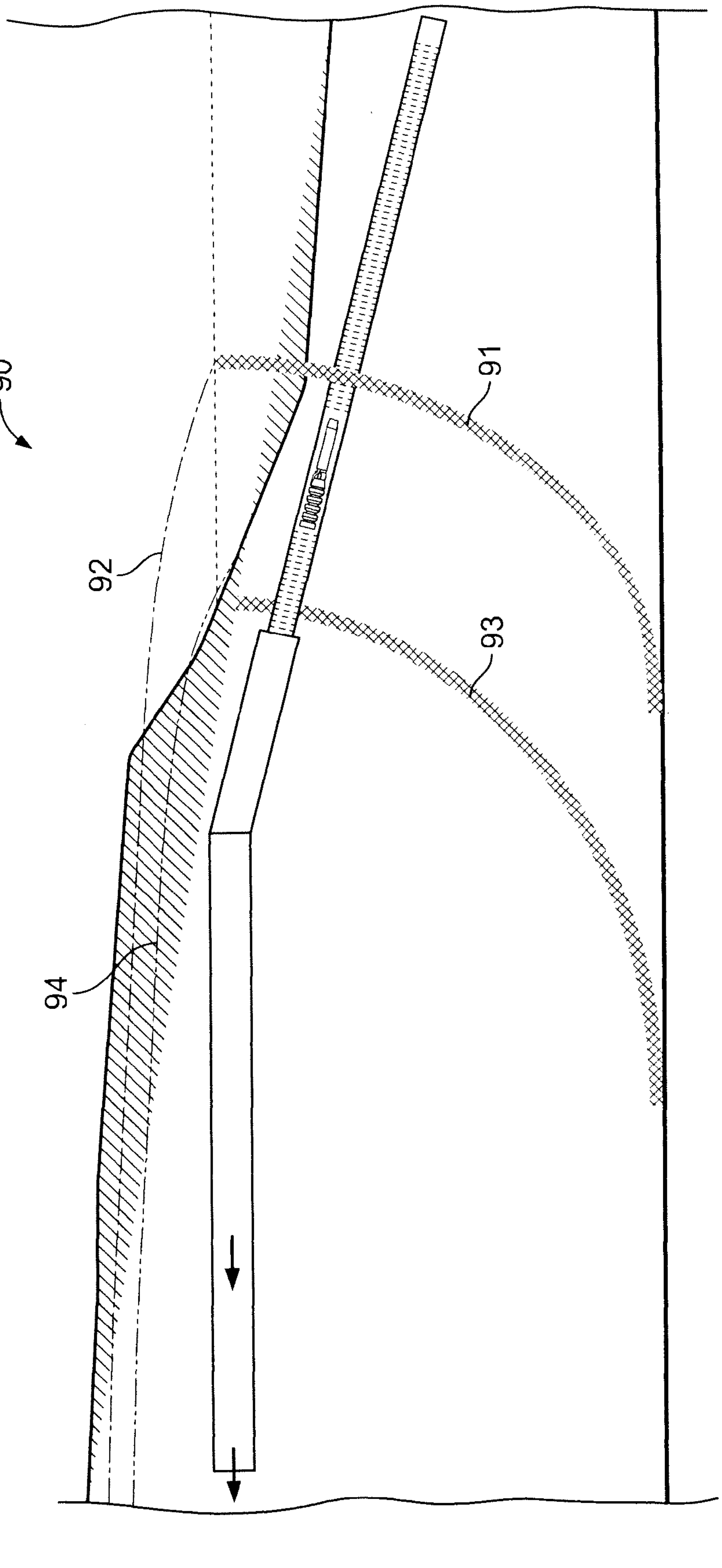


FIG. 16

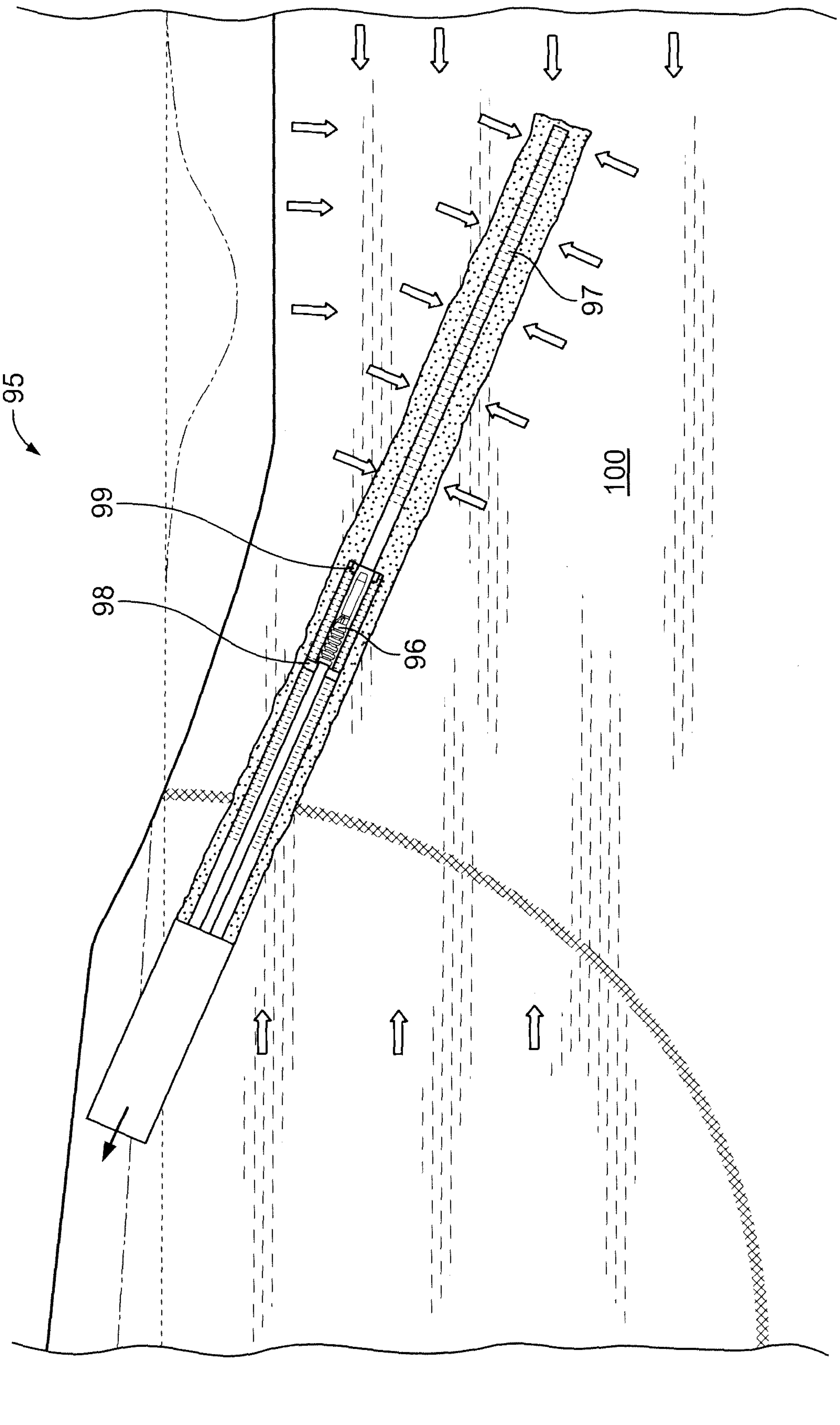


FIG. 17

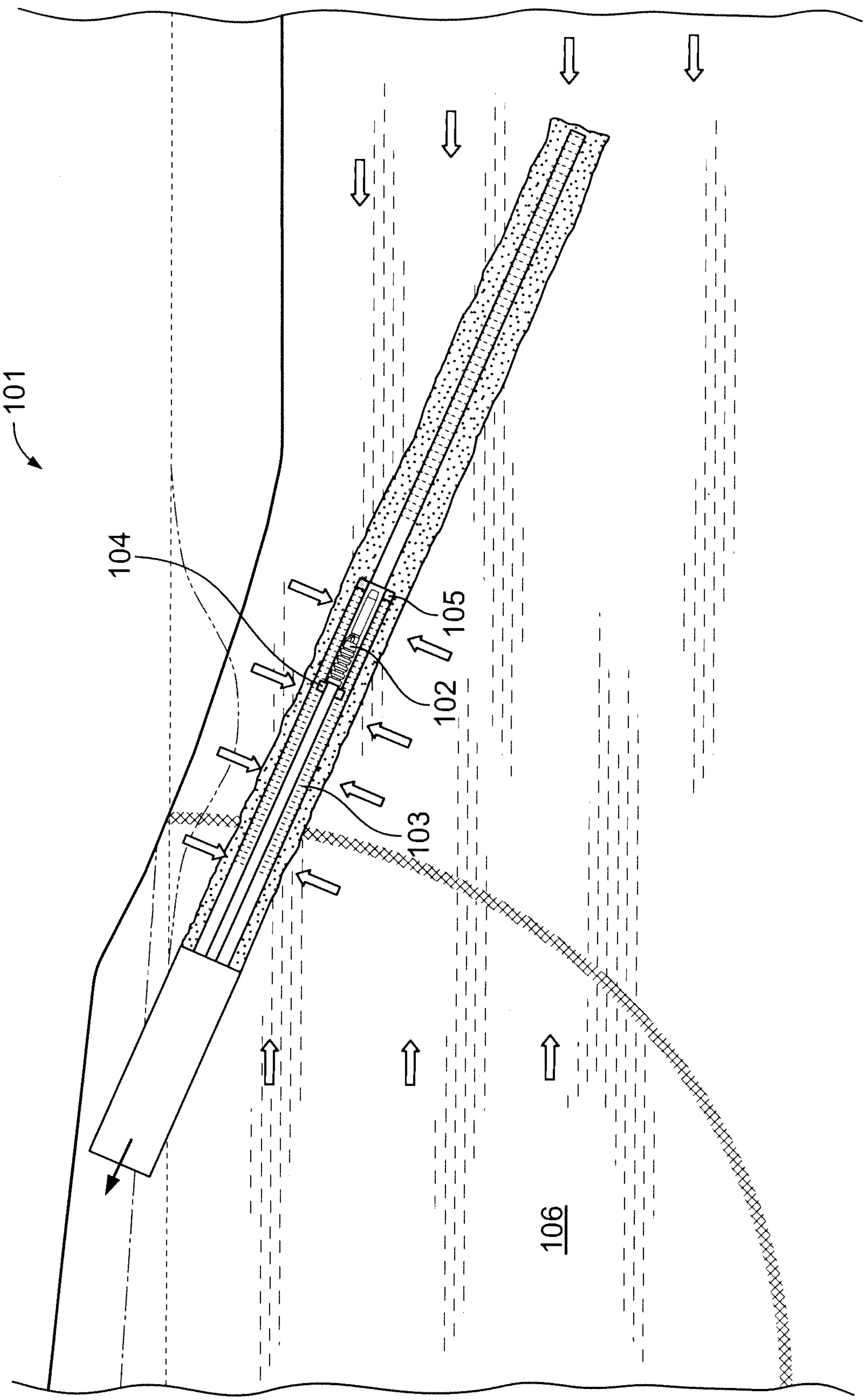


FIG. 18

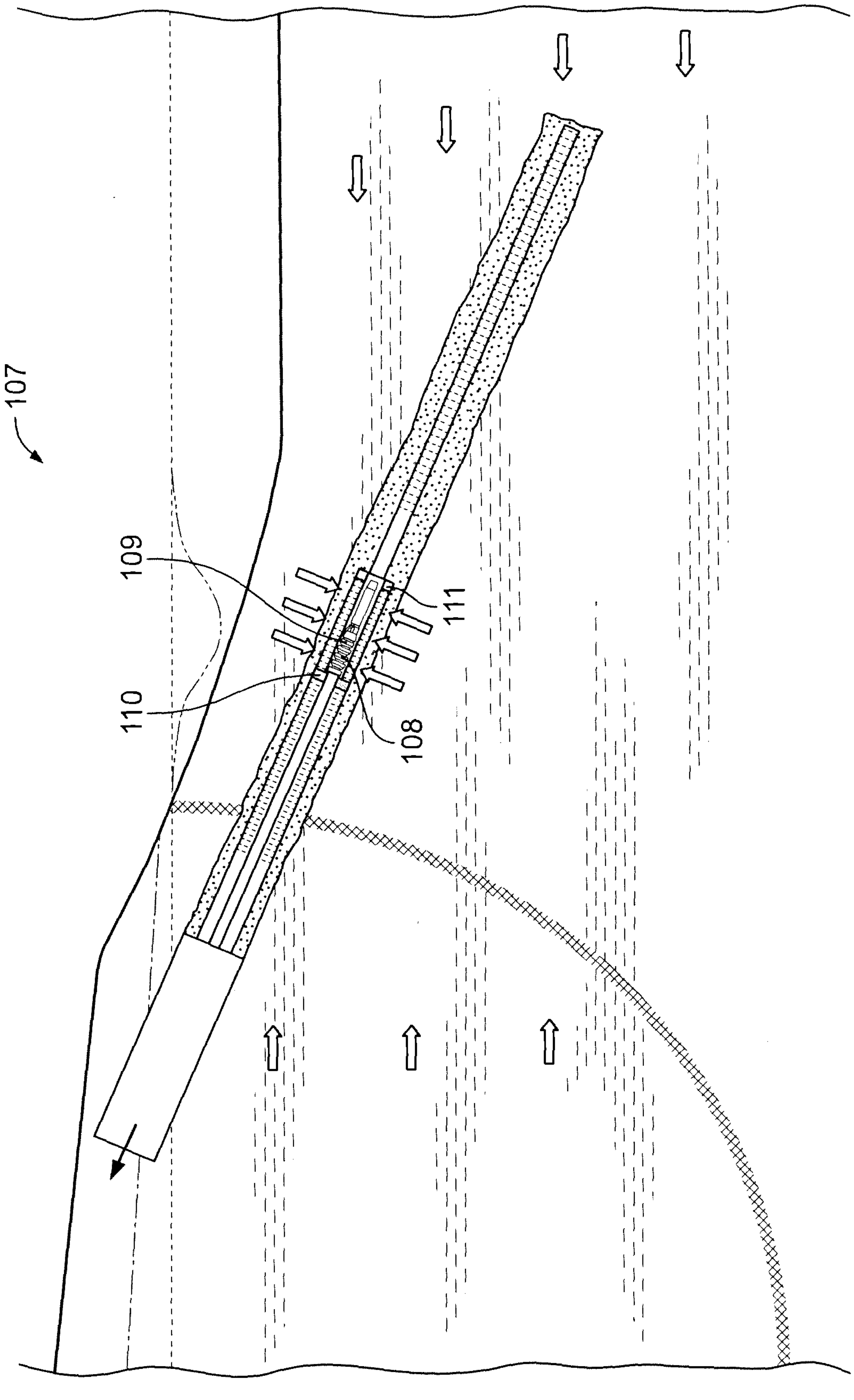


FIG. 19

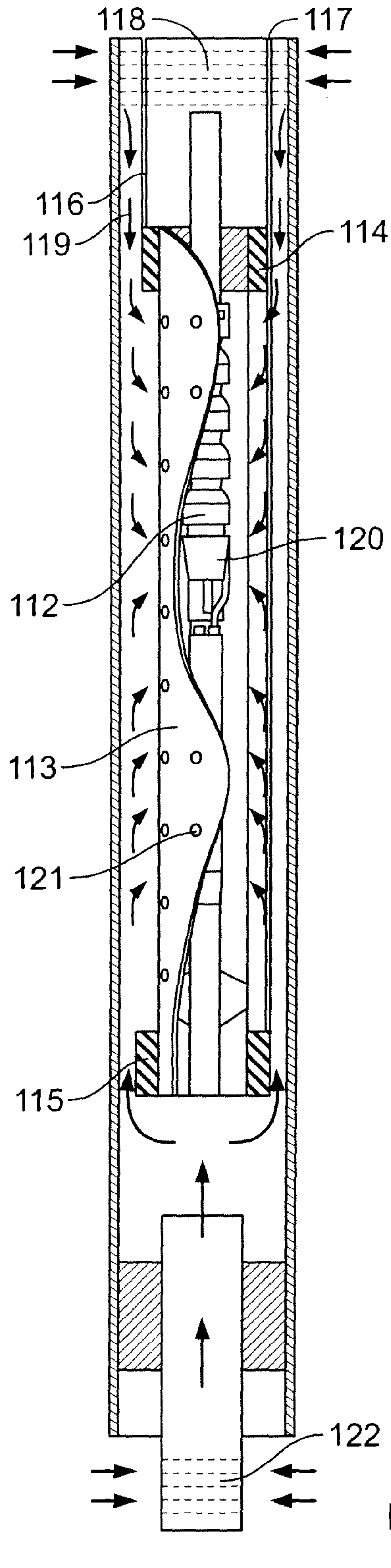


FIG. 20

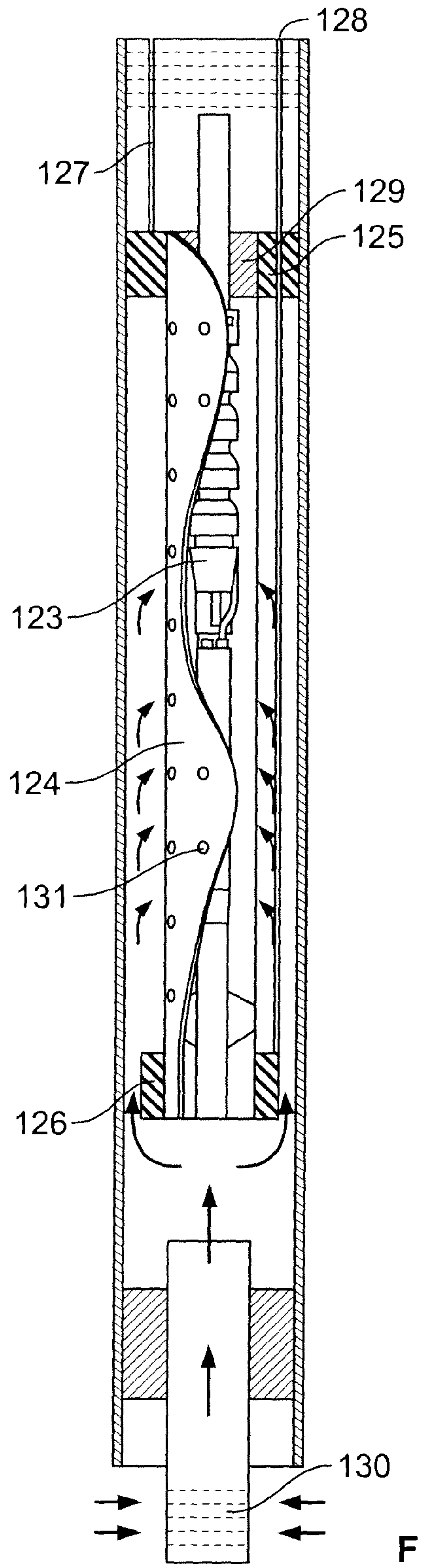


FIG. 21

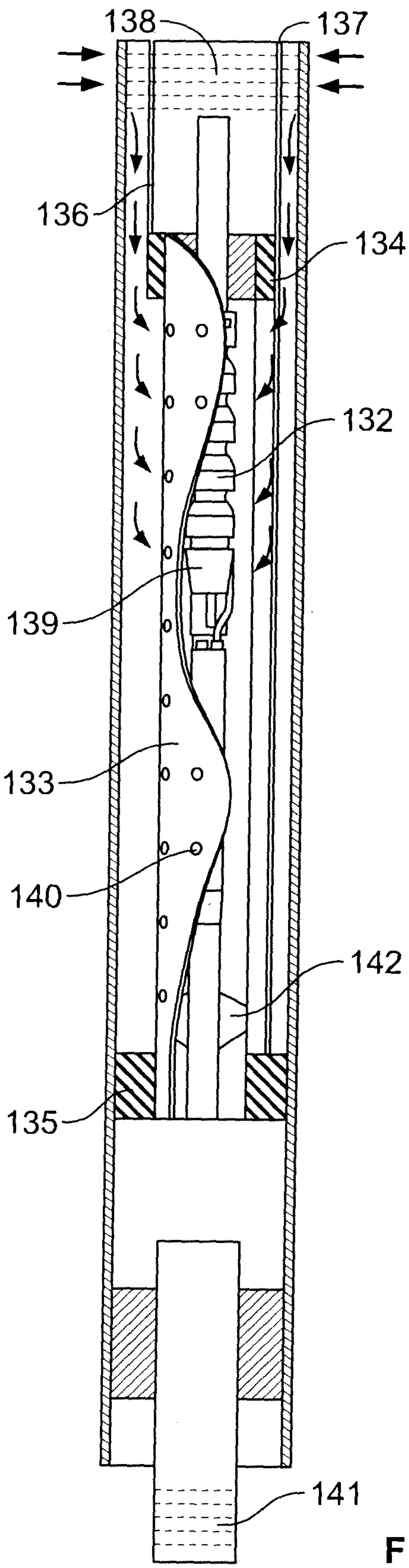


FIG. 22

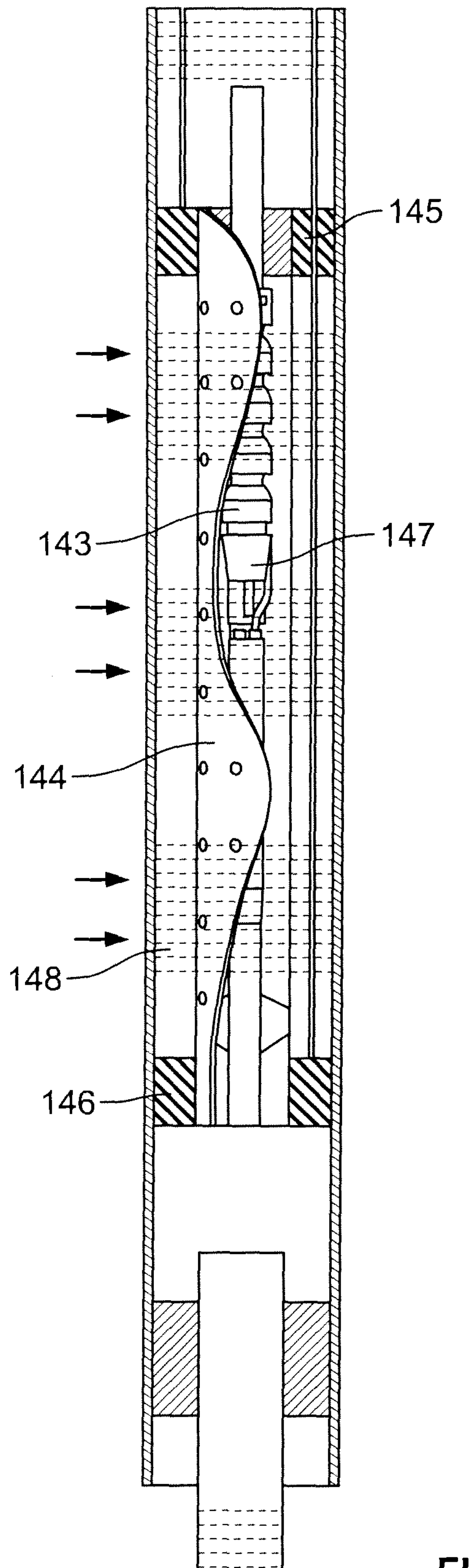


FIG. 23

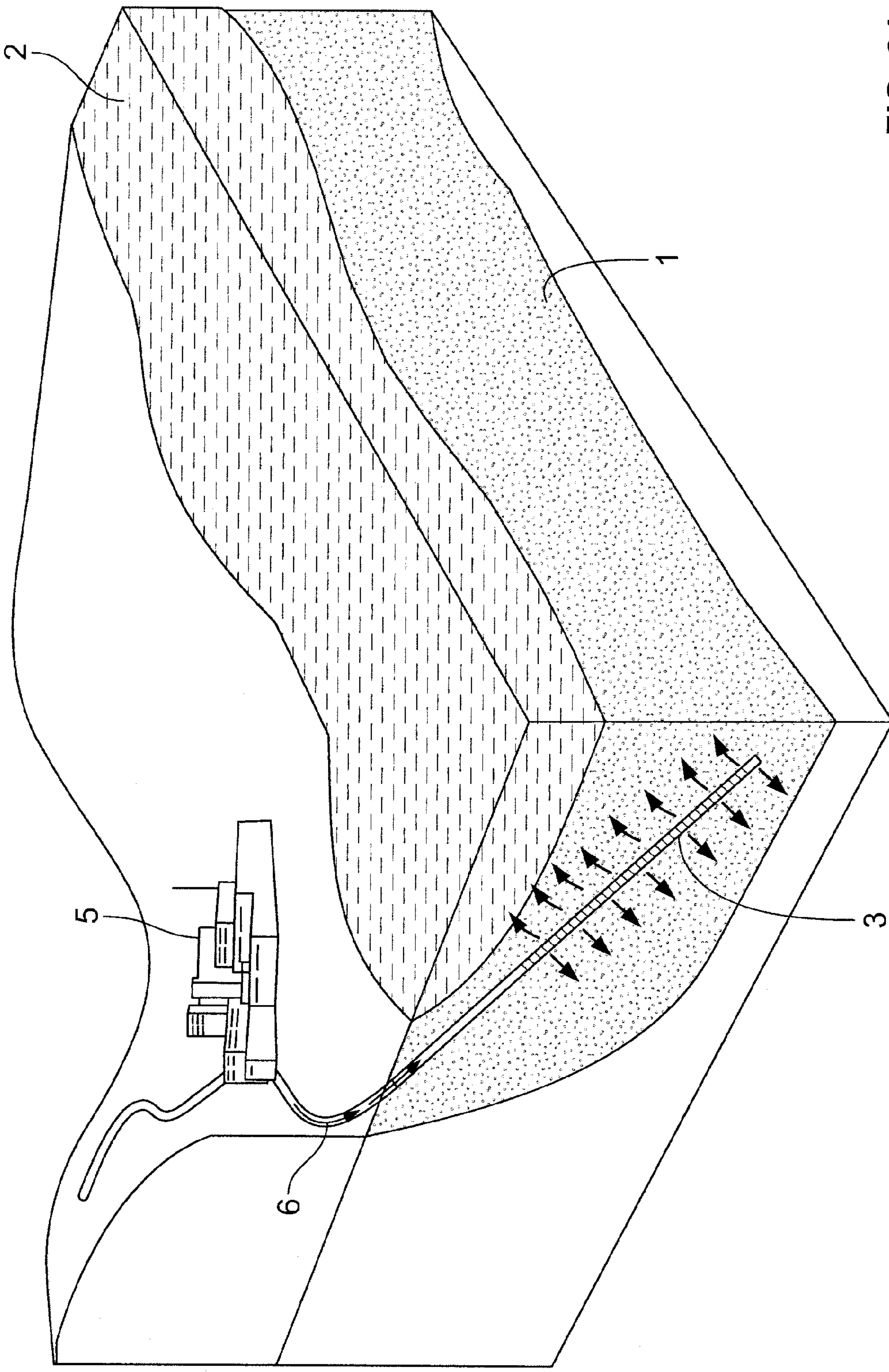


FIG. 24

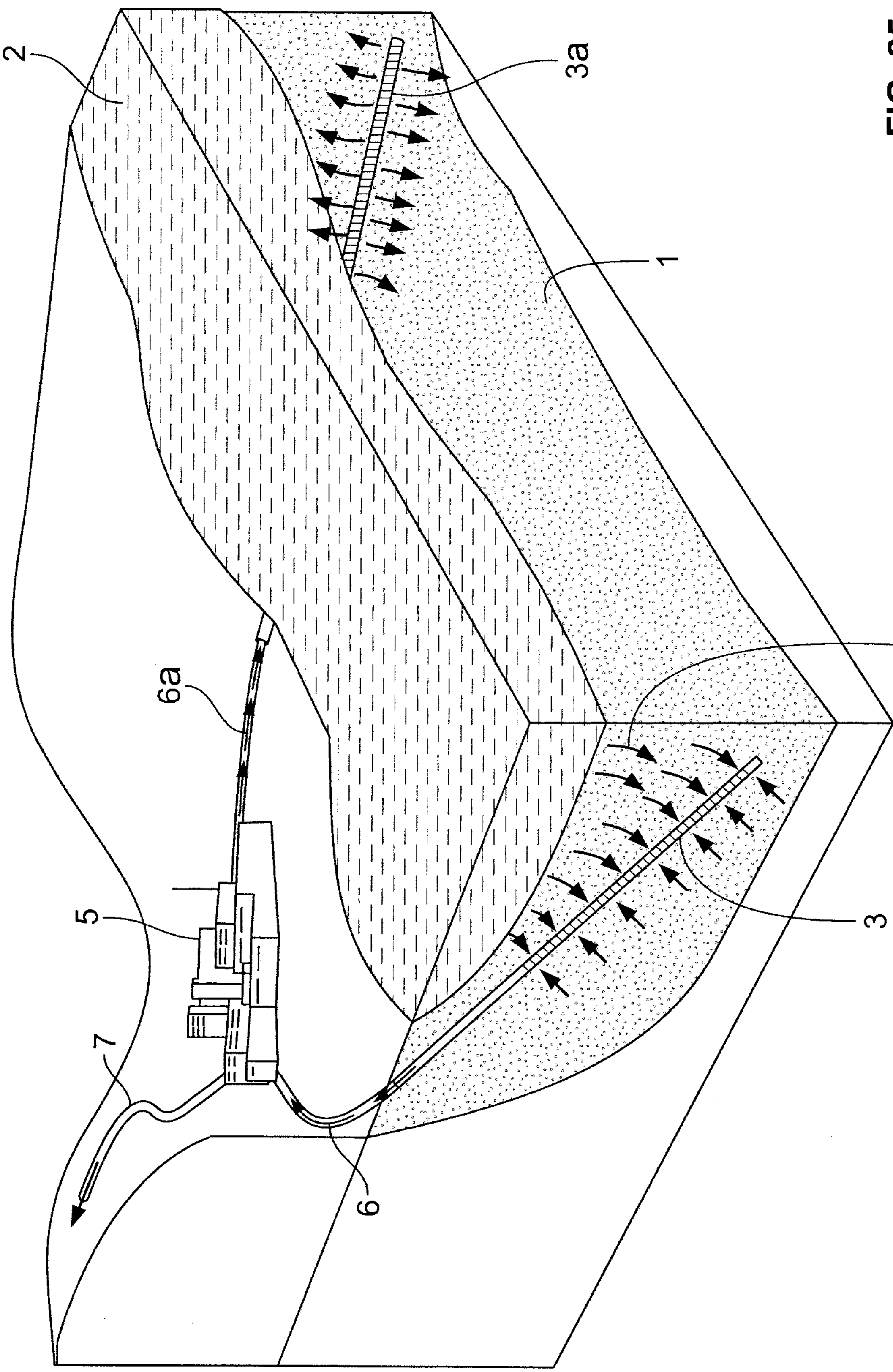


FIG. 25

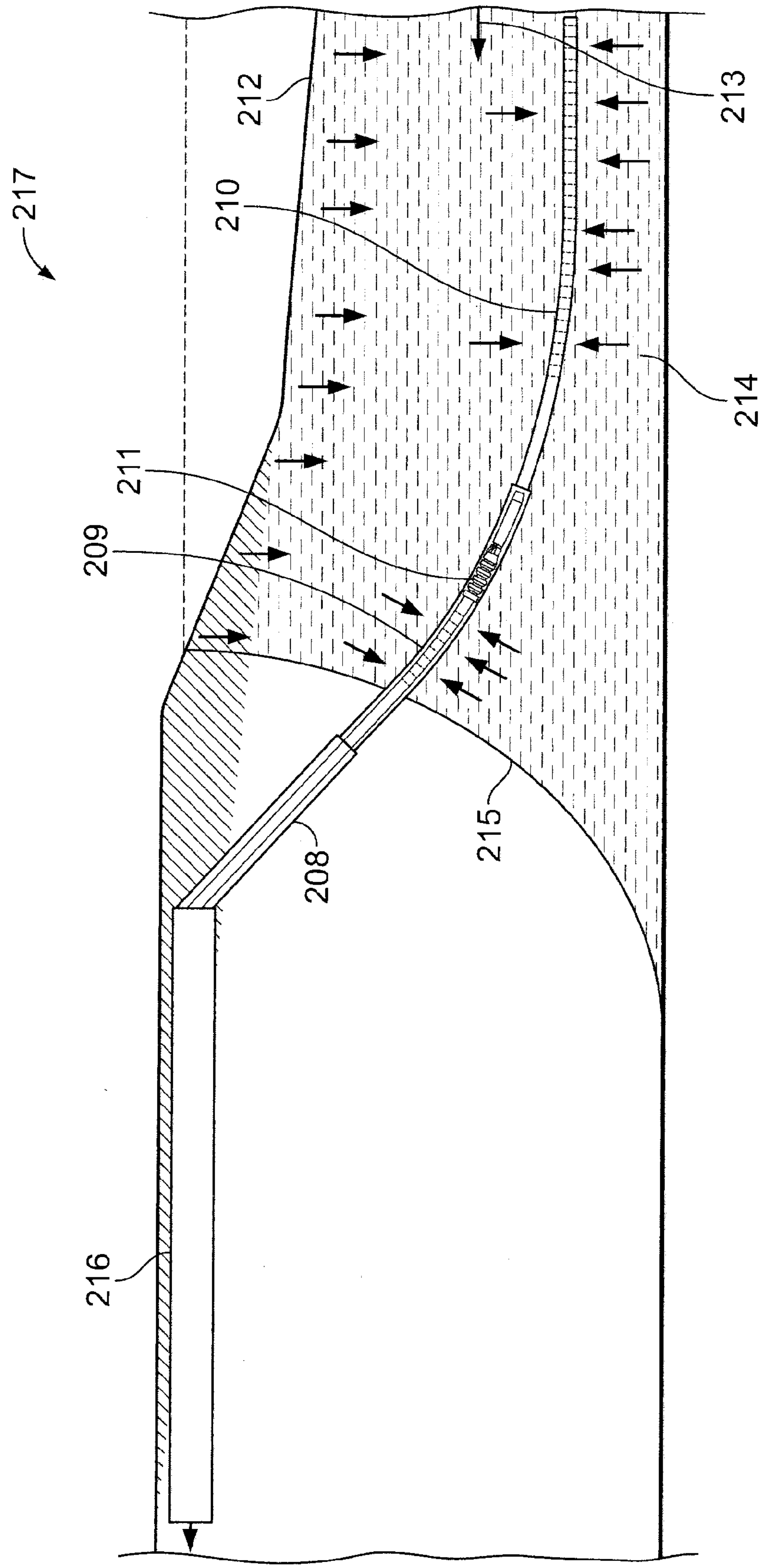


FIG. 26

DESALINATION SUBSURFACE FEEDWATER SUPPLY AND BRINE DISPOSAL

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a continuation-in-part of U.S. Pat. No. 8,056,629, filed by Dennis E. Williams on Mar. 29, 2010, which claims priority under 35 U.S.C. §119(e) to U.S. Provisional Application No. 61/293,134, filed by Dennis E. Williams on Jan. 7, 2010. Priority is claimed to these applications, the entire contents of which are herein incorporated by reference.

FIELD OF THE INVENTION

The invention relates generally to the field of supplying water from subsurface intake systems to desalination plants and concentrate disposal (e.g., injection of brine). More specifically, the invention relates to the construction of slant well systems or horizontally directionally drilled ("HDD") well systems to supply water from near-shore or subsea aquifers to desalination plants and to inject concentrate (e.g., desalination process brine) into subsea aquifers.

BACKGROUND OF THE INVENTION

Water developers in California and other coastal communities throughout the world are increasingly considering seawater desalination as a potential source of water for municipal and industrial supply. Limited ground water supplies in the coastal areas, poor inland ground water quality, and decreasing reliability of imported water have made seawater desalination a viable consideration. Seawater desalination has been made even more viable through more cost-effective and efficient subsurface intake systems and water treatment technologies.

Slant well drilling is included in the practice of drilling non-vertical wells. Non-vertical wells are typically used in the petroleum industry and are also known as horizontally directionally drilled wells (HDD wells). Slant wells are also used in other applications, such as drilling beneath roadways or rivers in order to provide conduits for facilities. Slant well desalination subsurface intake systems present significant advantages over traditional open water desalination plant intakes. These advantages include avoidance of entrainment and impingement impacts to marine life, reduction or elimination of costly reverse osmosis pretreatment, and reduction or elimination of permanent visual impacts. Slant well systems are buried systems (i.e. there are little or no visual impacts on the surface), as the wells and connecting pipelines are typically completed below the land surface.

In the past, slant well technology has not been successfully applied to subsea construction of desalination feedwater supplies, as the well screen slots have become clogged during pumping. Once the well screen slot openings are clogged, it becomes difficult or impossible to continue to pump water. Accordingly, there is a need for a reliable slant well system that is able to supply water from near-shore or subsea aquifers to a desalination plant without becoming clogged with fine-grained materials (e.g., fine sands and silts) over time. There is also a need for a method of constructing such a system—especially at low angles below horizontal in order to minimize impacts to inland fresh water sources. The present invention satisfies these needs and provides further related advantages, especially with regard to regulation of feedwater salinity.

SUMMARY OF THE INVENTION

The present invention is embodied in a system for supplying water to a desalination plant from a subsurface feedwater supply using one or more slant wells. The present invention is also embodied in a method for constructing a slant well feedwater supply system for supplying water from a subsurface feedwater supply. A system of angled wells (slant wells) is constructed. In one embodiment, the slant wells obtain a desalination feedwater supply from permeable aquifer systems near and/or beneath a saline water source (i.e., an ocean, sea, or salty inland lake). The slant wells induce recharge of the aquifer system through the floor of the ocean, sea, or inland lake due to the hydraulic head difference between the slant well pumping level and the level of the ocean, sea, or lake. As the supply source is relatively constant, the water supply to such a slant well system generally provides a long-term, sustainable water source for a desalination plant. The slant wells may be constructed at angles that vary from zero to ninety degrees below horizontal.

In one embodiment, the systems and methods discussed here are different from other non-vertical well applications in that they include an engineered, artificially filter-packed, angled well designed specifically to produce a high-capacity, low-turbidity desalination plant feedwater supply source from near-shore and offshore subsurface aquifer systems.

In one embodiment of the invention, the slant wells include a unique telescoping set of casings and screens. This design allows for a larger pump house casing near the land surface, with successively smaller casing and screen diameters as the well extends downward. The telescoping casings and screens facilitate extending the well to lineal lengths of 1,000 feet or greater beneath the floor of the saline water body, with angles below horizontal ranging from zero to ninety degrees.

In other, more detailed features of the invention, the slant well feedwater supply system may comprise a single slant well, an array of two or more slant wells, or multiple arrays of two or more slant wells, the location, spacing, and geometric layout of which may vary among feedwater intake sites depending upon the geohydrologic extent (horizontal and vertical) and characteristics of the subsurface aquifer materials, as well as upon the subsurface aquifer system salinity variation.

In another embodiment of the invention, an engineered artificial filter pack is placed around the well screen portions of the slant wells through a multi-step process that includes:

a. Placing the artificial filter pack in the annular space between the well screen and a temporary casing by pumping the filter pack material under pressure through one or more movable tremie pipes;

b. Placing a movable or temporary packer or blocking assembly within the bore of the well screen section near the portion of the well where the artificial filter pack is being placed;

c. Pumping water through the center of the well-screen packer assembly so that the water exits the well screen below the packer assembly and travels out of the well screen into the filter pack (water injection through the well-screen packer assembly helps to settle the filter pack, as well as ensure that the filter pack completely surrounds the well screen in the annular space between the well screen and the temporary casing);

d. Slowly withdrawing the tremie pipes and well-screen packer assembly up the screened portion of the well so that the artificial filter pack is placed along the length of the screened portion; and

e. Simultaneously withdrawing the temporary casing surrounding the well screen and filter pack by pulling, rocking and/or vibrating the casing.

Placement of the engineered artificial filter pack around the screened portions of the slant well helps stabilize the subsea aquifer materials and prevent migration of fine sand and silt materials (from subsea aquifers) into the well. This both inhibits the screen portions from becoming clogged and results in a desalination feedwater water quality, as measured by turbidity and silt density indices (a measure of fouling in reverse osmosis desalination systems), that eliminates or minimizes the need for pre-treatment of the water prior to desalination.

In one embodiment, the well screens are centered inside the temporary casings through a system of centralizers or screen centering guides.

The present invention is also embodied in a method of minimizing variations in feedwater salinity, the method comprising providing a plurality of slant wells, each having a different angle below horizontal. Shallower-angled wells tend to produce water having greater salinity, whereas steeper-angled wells tend to produce water having lesser salinity. By varying the amounts of water pumped from shallower-angled wells versus steeper-angled wells, variations in feedwater salinity that occur due to natural variations in the hydrologic cycle can be minimized. Natural variations in the hydrologic cycle (such as wet and dry hydrologic periods) can impact the location of the freshwater-saltwater interface due to variations in fresh water flowing from the land to the ocean, sea, or inland lake.

On one embodiment, multiple well screens are placed in a single slant well to minimize variations in feedwater salinity in that well that occur due to natural variations in the hydrologic cycle. The slant well can be equipped with a submersible pumping system fitted with a dual-packer shroud assembly. Using the dual-packer shroud assembly, the slant well can selectively pump from upper or lower portions of the subsea aquifer, thereby varying feedwater salinity as required to help minimize variations in feedwater salinity due to hydrologic cycles. The dual-packer shroud assembly (DPSA) allows selective production from well screens both above and below the packers (maximum production), well screens above the upper packer only (lower salinity), well screens below the lower packer only (higher salinity), or well screens between the packers (focused salinity).

Embodiments of the present invention include a telescoping slant well feedwater supply system for supplying water from an aquifer. The system comprises a primary well screen for admitting water from the aquifer (the primary well screen oriented along an axis angled below horizontal and having a substantially uniform cross-sectional area); a filter pack substantially surrounding the primary well screen; a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and a submersible pump contained within the pump house casing for pumping water admitted through the primary well screen. The cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

In another embodiment, the axis is straight. The system may further comprise a secondary well screen for admitting water from the aquifer, the secondary well screen oriented along the same axis but having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen. The system may additionally comprise a dual-valve assembly contained within the pump house casing. The dual-valve assembly may comprise a first valve for regulating the flow of water from the primary well screen to the submersible pump, and a second valve for regulating the flow of water from the secondary well screen to the submersible pump. In one embodiment, the first valve is a first pneumatic packer, and the second valve is a second pneumatic packer. The system may further comprise a first air line configured to extend from an air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer, and a second air line configured to extend from an air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer. The system may additionally comprise a tertiary well screen for admitting water from the aquifer, the tertiary well screen oriented along the axis between the first valve and the second valve. The dual-valve assembly may further comprise a shroud substantially surrounding the submersible pump. The shroud may have a plurality of holes through which water from the primary or secondary well screens can flow to the submersible pump. The dual-valve assembly may further comprise centering guides attached to the shroud for centering the submersible pump within the shroud.

Embodiments of the present invention also include a method of constructing a slant well feedwater supply system for supplying water from an aquifer. The method comprises the steps of placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings; placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings; and placing a filter pack in the space between the well screen and the one or more temporary casings.

In one embodiment, the method further comprises the step of withdrawing the one or more temporary casings. The step of placing the well screen may comprise the step of centering the well screen within the one or more temporary casings using centering guides. In the step of placing a telescoping plurality of casings, the telescoping plurality of casings may comprise a pump house casing. In one embodiment, the pump house casing has an upward end and a downward end, and the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing along the axis. The method may further comprise the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

In another embodiment, the step of placing the filter pack comprises the steps of extending one or more tremie pipes to the space between the well screen and the one or more temporary casings, and pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings. The step of extending the one or more tremie pipes may comprise the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides. In one embodiment, the one or more tremie pipes consist of three tremie pipes, and the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen. The step of placing the filter pack may further comprise the steps of placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer, and pumping water through the water pipe to settle the filter pack material. The method may further comprise the step of withdrawing the packer assembly and the one or more tremie pipes. The steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes may be gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

Embodiments of the present invention also include a method for reducing salinity variation in feedwater supplied from a slant well system comprising an upper well screen and a lower well screen for admitting water from an aquifer, a submersible pump for pumping water admitted through the upper or lower well screens, an upper valve for regulating water flow from the upper well screen to the submersible pump, and a lower valve for regulating water flow from the lower well screen to the submersible pump. The method comprises the steps of controlling the upper valve to inhibit water flow from the upper well screen to the submersible pump if the salinity of the feedwater decreases below a first predetermined threshold, and controlling the lower valve to inhibit water flow from the lower well screen to the submersible pump if the salinity of the feedwater increases above a second predetermined threshold. In one embodiment, the upper valve, in the step of controlling the upper valve, is a first pneumatic packer, and the lower valve, in the step of controlling the lower valve, is a second pneumatic packer.

The embodiments described above may alternatively be implemented using an HDD well.

In another exemplary system that embodies the invention, use of the slant or HDD wells can be used to dispose of water or brine that results from the desalination process. In one embodiment, construction of the slant or HDD well would be the same regardless of its use (extraction well or injection well) and would employ the same method of construction and placement of an artificial filter pack. In some conditions where the subsea aquifer does not require an engineered artificial filter pack, a natural filter pack comprising naturally occurring native (i.e., in situ) materials could be developed around the well screen portions of the slant or HDD well for the extraction (feedwater supply) or injection (concentrate return) process.

Other features of the invention should become more apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments of the present invention will now be described, by way of example only, with reference to the following drawings.

FIG. **1** is an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to an inland desalination plant, in accordance with an embodiment of the present invention. This embodiment may alternatively be implemented using an HDD well.

FIG. **2** is a side elevation view of a telescoped slant well having upper and lower well screens and showing water infiltration from the ocean and the freshwater-saltwater interface, in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casing cut away to show a submersible pump inside the pump house casing.

FIG. **3** is a side elevation view of a telescoped slant well having a single well screen interval and showing primary and secondary sources of water recharge to the slant well, in

accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screen shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing.

FIG. **4** is a side elevation view of a telescoped slant well having multiple screened intervals, in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show a submersible pump inside the pump house casing fitted with a dual-packer shroud assembly having both packers deflated for maximum well production.

FIGS. **5**A-**5**D are top plan views of four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration, a two-well array, a three-well array, and a four-well array, in accordance with embodiments of the present invention.

FIGS. **6**A and **6**B are top plan views of two slant well configurations, each having separate well head areas for the slant wells in the configuration, in accordance with embodiments of the present invention.

FIG. **7** is a side elevation view showing two telescoped slant wells extending from a common well head but at different angles below horizontal to produce water having different salinities (higher salinity production from the shallower-angle slant well and lower salinity production from the steeper-angle slant well), in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casings cut away to show submersible pumps inside the pump house casing.

FIG. **8** is a side elevation view of a telescoped slant well having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention.

FIG. **9** is a side elevation view of a telescoped slant well showing the placement of a single screened section centered within a temporary casing using centering guides and surrounded by an artificial filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

FIG. **10** is a side elevation view of a telescoped slant well illustrating the removal of the 20-inch diameter temporary casing surrounding the well screen and filter pack, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the well screen.

FIG. **11** is a side elevation view of a telescoped slant well having a single screened section with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the filter pack cut away to show the well screen.

FIG. **12** is a side elevation view of a telescoped slant well having dual screened intervals with the 20-inch and 22-inch temporary casings removed and a seal placed at the bottom of the 24-inch pump house casing, in accordance with an embodiment of the present invention, with the centering guides and filter pack cut away to show the well screen.

FIG. **13**A is a side elevation view of a telescoped slant well showing the placement of an artificial filter pack through a system of multiple tremie pipes in the annular space between the lower well screen and the temporary casing, in accordance with an embodiment of the present invention, with the casings, centering guides, and filter pack cut away to show the tremie pipies and upper and lower well screens. FIG. **13**B is a cross-section view of the telescoped slant well of FIG. **13**A, taken along the line **13-13** in FIG. **13**A, showing the temporary casing, upper well screen, filter pack, tremie pipes, and tremie pipe guides.

FIG. **14**A is a side elevation view of a telescoped slant well showing the placement and settlement of an engineered artificial filter pack through a multi-step process of placing the filter pack by pumping filter pack material through tremie pipes under pressure, simultaneously removing the temporary casing surrounding the tremie pipes, settling the filter pack using an in-screen packer assembly, and gradually withdrawing the in-screen packer assembly, in accordance with an embodiment of the present invention, with the casings and well screens cut away to show the in-screen packer assembly. FIG. **14**B is a detail view of the telescoped slant well of FIG. **14**A, showing the filter pack placement.

FIG. **15** is a chart of sieve opening versus percent of filter material passing the well screen slots for designing an engineered filter pack from site-specific samples of aquifer materials.

FIG. **16** is a side elevation view of a multiple-screened, telescoped slant well showing how the slant well can pump water with higher or lower salinity because of variations in the freshwater-saltwater interface due to natural variations in the hydrologic cycle, in accordance with an embodiment of the present invention, with the pump house casing cut away to show a submersible pump inside the pump house casing.

FIG. **17** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the lowermost screen only (upper packer inflated, lower packer deflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **18** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the uppermost screen only (upper packer deflated, lower packer inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **19** is a side elevation view of a multi-screened, telescoped slant well equipped with a submersible pump fitted with a dual packer shroud assembly and pumping from the well screen portion between the dual packers (upper and lower packers inflated), in accordance with an embodiment of the present invention, with the aquifers and artificial filter pack surrounding the well screens shown in cross-section, and the pump house casing cut away to show the submersible pump and dual-packer shroud assembly.

FIG. **20** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for maximum production (both upper and lower packers deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **21** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from below the lower packer (upper packer inflated and lower packer deflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **22** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from above the upper packer (upper packer deflated and lower packer inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **23** is a detailed side elevation view of a portion of a well having a submersible pump fitted with a dual packer shroud assembly configured for production from between the dual packers (both upper and lower packers inflated), in accordance with an embodiment of the present invention, with portions of the well cut away to show the submersible pump.

FIG. **24** is an isometric block drawing illustrating a slant or HDD well concentrate disposal system injecting water or brine from a desalination plant into a subsurface aquifer system below the ocean floor.

FIG. **25** is an isometric block drawing illustrating a slant or HDD well feedwater supply system and a slant or HDD well concentrate disposal system.

FIG. **26** is a side elevation view of a telescoped HDD well, in accordance with an embodiment of the present invention, with the aquifers shown in cross-section and the pump house casing cut away to show a submersible pump inside the pump house casing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is generally embodied in a slant or HDD well, or system of slant or HDD wells, that produces water from permeable deposits near or beneath saline water bodies (e.g., oceans, seas, or inland lakes) or injects concentrate return into deposits beneath saline water bodies. The invention can provide a long-term, sustainable feedwater supply for a desalination plant with virtually unlimited recharge potential.

With reference now to the illustrative drawings, and particularly to FIG. **1**, there is shown an isometric diagram illustrating a slant well feedwater supply system for producing water from a subsurface aquifer system below an ocean floor and pumping the feedwater to a desalination plant, in accordance with an embodiment of the present invention. Permeable materials comprising the subsea aquifer **1** are recharged from the overlying ocean **2**. The slant well **3** receives recharge from induced infiltration of ocean water **4** and pumps this feedwater to a desalination plant **5** through a pipeline **6**. The desalination plant **5** pumps out freshwater through a freshwater pipeline **7** to meet inland water supply demands.

FIG. **24** shows a slant or HDD well concentrate disposal system from a desalination plant into subsurface materials. Permeable materials comprising the subsea aquifer **1** receive the injected water from the slant or HDD well **3** (or a plurality of slant or HDD wells). The slant or HDD well **3** injects concentrate return from the desalination plant **5**. The concentrate return is pumped to the slant or HDD injection well **3** through the pipeline **6**.

FIG. **25** shows a slant or HDD well feedwater supply system and a slant or HDD well concentrate disposal system. Permeable materials comprising the subsea aquifer **1** supply water to the slant or HDD well **3**. Feedwater is pumped to the desalination plant **5** through the pipeline **6**. Desalination concentrate return (e.g., brine) is injected into the subsurface aquifer system **1** via the pipeline **6**_a_ through the concentrate return injection well (slant or HDD) **3**_a_.

With reference now to FIG. **2**, there is shown a telescoped slant well **8** configured for use in a feedwater supply system **17**, in accordance with an embodiment of the present invention. In one embodiment, the slant well is drilled at a low angle below horizontal using a dual rotary drilling rig or other suitable device to a total lineal length of approximately 1,000 feet or more. In one particular embodiment, the slant well is drilled at an angle of approximately 23 degrees below horizontal. The telescoped slant well has an upper well screen **9** and a lower well screen **10** for admitting water from a saltwater aquifer **14**. A submersible pump **11** pumps water out of the slant well to a desalination plant. The slant well is recharged from induced infiltration of water **13** that flows from the ocean floor **12** and lateral offshore sources through the saltwater aquifer **14**. The saltwater aquifer meets the freshwater aquifer beneath the land surface at a freshwater-saltwater interface **15**. Saline water is pumped from the slant well **8** to the desalination plant via an underground pipeline **16** connected to the buried slant well head. In one embodiment, the buried slant well head is connected to the pipeline **16** via a caisson (not shown) sunk into the land surface.

The slant well **8** is part of a feedwater supply system **17** that comprises the slant well and the pipeline **16**. Because the slant well is buried beneath the land surface and ocean floor, the feedwater supply system avoids entrainment and impingement impacts to marine life. Additionally, the filtration process performed by the subsurface aquifer **14** reduces or eliminates costly reverse osmosis pretreatment that would otherwise need to be performed at a desalination plant. Furthermore, because the slant well is completed below the land and ocean surface, aesthetic impacts are minimized or eliminated.

FIG. **26** shows a telescoping HDD well system **208** completed with two screen sections **209** and **210**. The submersible pump **211** pumps water from the well, which is recharged from induced infiltration from the ocean floor **212** and lateral off-shore sources **213** that flow into the salt water aquifer **214**. The fresh water-salt water interface is shown by the number **215**. Saline water is pumped from the HDD well **208** to the desalination plant via the pipeline **216**. The HDD well feedwater supply system **217** avoids entrainment and impingement impacts to marine life. In addition, the filtration process of the subsurface aquifer materials **214** reduces or eliminates costly reverse osmosis pretreatment. Furthermore, the HDD well system may be completed below the land surface to eliminate aesthetic impacts.

Various configurations of a slant well for use in a feedwater supply system will now be described in more detail. With reference to FIG. **3**, there is shown a telescoped slant well **18** having an artificial filter pack **19** and a single well screen interval **20** in accordance with an embodiment of the present invention. The slant well extends through the freshwater-saltwater interface **21**. A primary recharge flow **22** and secondary recharge flow **23** provide recharge to the slant well. Sustained recharge to the slant well is largely provided by induced recharge from the ocean through the primary recharge flow **22** due to the hydraulic head difference between the ocean level **24** and the slant well pumping level **25**. The location of the freshwater-saltwater interface **21** is governed by the height of the freshwater elevation **26**.

A slant well in accordance with the present invention can have multiple screened intervals for providing greater flexibility in feedwater production. With reference to FIG. **4**, there is shown a telescoped slant well **27** having an artificial filter pack **28**, multiple screened intervals **29** (upper and lower), and a submersible pump **30** fitted with a dual-packer shroud assembly, in accordance with an embodiment of the present invention. In the configuration shown in FIG. **4**, both of the dual packers are deflated so that water is drawn into the well through both the upper and lower screened intervals. This configuration is for maximum feedwater production. In other configurations, one or both of the dual packers can be inflated so that water is drawn into the well through less than the full length of the screened intervals. These other configurations are described in greater detail below with respect to FIGS. **17-23**.

A feedwater supply system in accordance with the present invention can comprise a plurality of slant wells. With reference to FIGS. **5**A-**5**D, there are shown four slant well configurations, each having a common well head area for the slant wells in the configuration, the configurations including a single well configuration **31**, a two-well array **32**, a three-well array **33**, and a four-well array **34**, in accordance with embodiments of the present invention. In each configuration, the slant wells all begin in the same vicinity of each other, i.e., they have common well head area **35**. As shown in FIGS. **5**A-**5**D, the well head area is located above the high tide line to maximize the undersea screened portion **36** of the slant wells.

With reference now to FIGS. **6**A and **6**B, there are shown a parallel slant well configuration **37** and a nonparallel slant well configuration **38**, in accordance with embodiments of the present invention. Each of these slant well configurations has a separate well head area for the slant wells in the configuration.

With reference now to FIG. **7**, there are shown a shallower-angle slant well **39** and a steeper-angle slant well **40**, the slant wells extending from a common wellhead area **41** but at different angles α_1 and α_2 below horizontal to produce water having different salinities, in accordance with an embodiment of the present invention. The freshwater-saltwater interface **44** is also shown to illustrate higher salinity production from the shallower-angle slant well **39** and lower salinity production from the steeper-angle slant well **40**.

Construction of a slant well for use in a feedwater supply system will now be described in more detail. In one embodiment, the initial construction of the slant well involves placing a telescoping plurality of casings beneath the land surface and ocean floor. With reference to FIG. **8**, there is shown an initial step in the construction of a telescoped slant well **45** having successively reduced casing diameters, the well extending to a lineal length of approximately 1,000 feet, in accordance with an embodiment of the present invention. The slant well comprises a 26-inch permanent casing **46** for the sanitary seal, a 24-inch permanent pump house casing **47**, a 22-inch temporary casing **48**, and a 20-inch temporary casing **49**.

With reference now to FIG. **9**, there is shown a second step in the construction of a telescoped slant well **50** having a single 12-inch-diameter well screen section **51**, in accordance with an embodiment of the present invention. An artificial filter pack **52** has been placed around the well screen section. The well screen section has been centered within a 20-inch temporary casing **54** using centering guides **53**.

Before operating a slant well in accordance with the present invention, the temporary casings surrounding the artificial filter pack and well screen section need to be withdrawn. FIGS. **10** and **11** illustrate the process of removing a 20-inch and 22-inch temporary casings from a telescoped slant well having a single well screen section. FIG. **10** shows a telescoped slant well **55** having a single well screen section **56** surrounded by an artificial filter pack **57** and centered using centering guides **58**. Dashed line **59** shows the extent of the 20-inch temporary casing prior to the start of the removal process. FIG. **11** shows a telescoped slant well **60** having a single well screen section **61** with both the 20-inch and 22-inch temporary casings removed. The top of the well screen **62** is cut off within the 24-inch pump house casing **63**, which is fitted with a seal **64** at the bottom of the pump house casing.

With reference now to FIG. **12**, there is shown a telescoped slant well **65** having dual screened intervals **66** and the temporary casings removed, in accordance with an embodiment of the present invention. Dashed line **67** shows the extent of the 20-inch temporary casing prior to the start of the removal process. The top of the well screen **68** is cut off within the 24-inch pump house casing, which is fitted with a seal **69** at the bottom of the pump house casing.

Before completing construction of a slant well in accordance with the present invention, the artificial filter pack needs to be placed and settled around the well screen sections. With reference to FIGS. **13**A and **13**B, there is shown a telescoped slant well **70** with an artificial filter pack **71** being placed through a system of multiple tremie pipes **72** in the annular space between the lower well screen **73** and the temporary casing **74**, in accordance with an embodiment of the present invention. The tremie pipes **72** are positioned using tremie pipe guides **75**, **76**, **77** and **78**.

FIGS. **14**A and **14**B further illustrate the process of placing and settling the artificial filter pack. These figures show a telescoped slant well **79** with an artificial filter pack **80** being placed and settled through a multi-step process. The filter pack is placed by pumping filter pack material **81** through the multiple tremie pipes **82** under pressure. Simultaneously, the temporary casing **83** surrounding the tremie pipes is removed and the filter pack **80** is settled using an in-screen packer assembly **84**. The in-screen packer assembly is configured to be slid inside a well screen. A water pipe extends from a water pump (not shown) through a hole in the in-screen packer. The water pump may be a standard water pump known to persons of ordinary skill in the art, with sufficient flow and pressure to cause water at the depth below the packer to flow outward through the well screen portion below the packer, thereby settling the filter pack in the vicinity of the packer. The in-screen packer assembly and tremie pipes are gradually withdrawn so that the artificial filter pack is placed and settled along the entire length of the well-screen portion of the slant well.

An engineered filter pack is designed to stabilize the subsea aquifer materials and, after proper development, prevent migration of fine sand and silt materials from the subsea aquifer into the well. With reference to FIG. **15**, there is shown an example chart of sieve opening versus percent of filter material passing the well screen slots for designing an engineered filter pack (line **85**) from site-specific samples of aquifer materials (line **86**) using the Terzaghi Migration Factor **87** as well as the filter pack sorting factor **88** and percentage of filter material passing the well screen slots **89**. This figure illustrates the principles behind the design of the artificial filter pack. A key purpose of the filter pack is to stabilize the aquifer. A key purpose of the well screen is to stabilize the filter pack.

To design the engineered filter pack, site-specific samples of aquifer materials are taken. It is next determined what sieve opening would pass 85 percent of the aquifer materials in the finest zone. In the example shown in FIG. **15**, it is determined that a sieve opening of approximately 0.6 millimeters would pass 85 percent of the finest aquifer materials within the screened interval of the well. The grain sizes of the filter pack are then chosen such that the 15-percent-passing filter pack size is no more than four times greater than the 85-percent-passing size of the finest aquifer materials within the screened section of the well. In the example of FIG. **15**, the 15-percent-passing filter pack size is 2.4 mm. The well screen slot openings are then sized such that 15 to 20 percent of the filter pack material will theoretically pass through the well screen slots. In the example shown in FIG. **15**, a well screen having approximately 0.094-inch (3/32-inch or 2.4-millimeter) slots is chosen. The uniformity coefficient (60 percent passing/10 percent passing) of the filter pack is typically about half the uniformity coefficient of the aquifer This ratio is known as the Sorting Factor.

As indicated above a slant well in accordance with the present invention can have multiple screened intervals and a dual-packer shroud assembly for providing greater flexibility in feedwater production. This flexibility can become important because of variations in the freshwater-saltwater interface due to national variations in the hydrologic cycle and a need to provide water of uniform salinity to a desalination plant. With reference to FIG. **16**, there is shown a multiple-screened, telescoped slant well **90** having multiple well screens, in accordance with an embodiment of the present invention. FIG. **16** illustrates how, without a means to vary the intake locations, a slant well can pump water with higher or lower salinity because of variations in the freshwater-saltwater interface due to natural variations in the hydrologic cycle. During wet hydrologic cycles, the freshwater-saltwater interface (line **91**) is farther from the shore due to the higher freshwater hydraulic head (line **92**). During dry hydrologic periods, the freshwater-saltwater interface (line **93**) is closer to the shore due to a lower freshwater hydraulic head (line **94**). The movement of the freshwater-saltwater interface is generally governed by the Ghyben-Herzberg principle, i.e., the depth to the interface (below sea level) is forty times the height of the freshwater head above sea level.

As will now be described, multiple screened intervals and a dual-packer shroud assembly can provide greater flexibility in feedwater production and lessen the effects of variations in the hydrologic cycle. With reference to FIG. **17**, there is shown a multi-screened, telescoped slant well **95** equipped with a submersible pump **96** fitted with a dual-packer shroud assembly and pumping from the lowermost screen **97** only (upper packer **98** inflated, lower packer **99** deflated), in accordance with an embodiment of the present invention. This configuration allows for greater production from the more saline portion **100** of the aquifer.

With reference now to FIG. **18**, there is shown a multi-screened, telescoped slant well **101** equipped with a submersible pump **102** fitted with a dual-packer shroud assembly and pumping from the uppermost screen **103** only (upper packer **104** deflated, lower packer **105** inflated), in accordance with an embodiment of the present invention. This configuration allows for greater production from the less saline portion **106** of the aquifer.

With reference now to FIG. **19**, there is shown a multi-screened, telescoped slant well **107** equipped with a submersible pump **108** fitted with a dual-packer shroud assembly and pumping from the well screen portion **109** between the dual packers (upper packer **110** and lower packer **111** inflated), in accordance with an embodiment of the present invention. This configuration allows for focused production from the portion of the aquifer proximate the well screen portion **109**.

The various configurations of the dual packer shroud assembly will now be described in greater detail with reference to FIGS. **20-23**. FIG. **20** shows a portion of a well having a submersible pump **112** fitted with a dual-packer shroud assembly **113**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **114** and a lower packer **115**. In FIG. **20**, the dual-packer shroud assembly is configured for maximum production (both upper packer **114** and lower packer **115** deflated). The upper packer is inflated and deflated using an upper packer air line **116**. The lower packer is inflated and deflated using a lower packer air line **117**. When both packers **114** and **115** are deflated, water enters the upper screen **118** from the aquifer and travels downward toward the pump in the annular space **119** between the upper screen and the pump discharge pipe. This upper water passes by the upper packer **114**, which is deflated, and enters the pump intake **120** through holes **121** in the shroud assembly. Water entering through the lower screen **122** from the aquifer travels upward toward the pump and passes by the lower packer **115**, which is deflated, and enters the pump intake through the holes **121** in the shroud assembly.

FIG. **21** shows a portion of a well having a submersible pump **123** fitted with a dual-packer shroud assembly **124**, in accordance with an embodiment of the present invention. The shourd assembly comprises two pneumatic packers: an upper packer **125** and a lower packer **126**. In FIG. **21**, the dual-packer shroud assembly is configured for production from below the lower packer (upper packer **125** inflated and lower packer **126** deflated). The upper packer is inflated and deflated using an upper packer air line **127**. The lower packer is inflated and deflated using a lower packer air line **128**. Water entering through the upper well screen is prevented from entering the pump intake by means of a permanent packer **129** and the inflated upper packer **125**. Water entering through the lower screen **130** from the aquifer travels upward toward the pump and passes by the lower packer **126**, which is deflated, and enters the pump intake through the holes **131** in the shroud assembly.

FIG. **22** shows a portion of a well having a submersible pump **132** fitted with a dual-packer shroud assembly **133**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **134** and a lower packer **135**. In FIG. **22**, the dual-packer shroud assembly is configured for production from above the upper packer (upper packer deflated **134** and lower packer inflated **135**). The upper packer is inflated and deflated using an upper packer air line **136** extending from an air pump (not shown) to the upper packer. The lower packer is inflated and deflated using a lower packer air line **137** extending from an air pump (not shown) to the upper packer. The air pump may be a standard air pump known to persons of ordinary skill in the art, sufficient to displace a volume of gas by physical or mechanical action to inflate and deflate the upper and lower packers. Water entering through the upper screen **138** from the aquifer travels downward toward the pump intake **139** and passes by the upper packer **134**, which is deflated, and enters the pump intake **139** through the holes **140** in the shroud assembly. Water entering through the lower well screen **141** is prevented from entering the pump intake by means of the inflated lower packer **135**. Guides **142** center the pump within the dual-packer shroud assembly.

FIG. **23** shows a portion of a well having a submersible pump **143** fitted with a dual-packer shroud assembly **144**, in accordance with an embodiment of the present invention. The shroud assembly comprises two pneumatic packers: an upper packer **145** and a lower packer **146**. In FIG. **23**, the dual-packer shroud assembly is configured for production from between the dual packers (both upper packer **145** and lower packer **146** inflated). The upper packer is inflated and deflated using an upper packer air line. The lower packer is inflated and deflated using a lower packer air line. Water enters the pump intake **147** from the screened section **148** between the packers. Water entering through the upper or lower well screens is prevented from entering the pump intake by means of the inflated upper packer **145** and lower packer **146**.

A slant well feedwater supply system in accordance with the present invention can be constructed near and/or beneath any saline water source, but more preferably is constructed where a river delta deposit meets the ocean, where a major drainage (such as a creek, stream or river) discharges into the ocean, or where an aquifer system under a land surface extends offshore. An initial field investigation is preferably conducted to determine the potential of a site to yield water for a desalination plant. This exploratory work may involve drilling boreholes and test wells to an appropriate depth both onshore and offshore to properly characterize the subsurface aquifer system, which may typically be sand and gravels but may also include secondary porosity features in consolidated rock aquifers (e.g. carbonate aquifers). In one embodiment, the boreholes and test wells are drilled 50 to 200 feet deep. The lithologic characterization of the aquifers may also indicate the quality of the water that might be supplied for a well drilled at that site (e.g., in terms of total dissolved solids (TDS), chlorides and other chemical constituents of concern in a desalination feedwater supply and how those constituents vary with depth).

In one embodiment, the slant well feedwater supply system extends at approximately a 23-degree angle below horizontal to a total length of approximately 350 feet and is capable of providing 2,000-gpm feedwater supply having an average silt density index of approximately 0.58 and an NTU between approximately 0.15 and 0.33. Of the total length, the first approximately 130 feet can comprise a blank casing, followed by approximately 220 feet of a well screen. The well screen can comprise a plurality of Roscoe Moss Full-Flo louver well screens having 3/32-inch slots, the plurality welded together end-to-end to form the complete well screen. The well screen and blank casing can have an inner diameter of 12 1/8 inches and a wall thickness of 5/16-inches. In one embodiment, the well screen and blank casing comprise 316L stainless steel. The artificial filter pack can comprise Colorado Silica 1/4×16 packed approximately 5 inches thick around the well screen. In one particular embodiment, the full scale system comprises a plurality of seven 1,000-foot slant wells, with each well supplying a feedwater supply of approximately 3,000 gpm for a total supply of approximately 30 mgd.

The foregoing detailed description of the present invention is provided for purposes of illustration, and it is not intended to be exhaustive or to limit the invention to the particular embodiments disclosed. The embodiments may provide different capabilities and benefits, depending on the configuration used to implement the key features of the invention. Accordingly, the scope of the invention is defined only by the following claims.

What is claimed is:

1. A telescoping slant well system for returning water to a subsurface aquifer system, the well system comprising:
- a primary well screen for injecting water into the aquifer system, the primary well screen oriented along an axis angled less than ninety degrees below horizontal and having a substantially uniform cross-sectional area;
- a filter pack substantially surrounding and adjacent to the primary well screen;
- a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area; and

a submersible pump contained within the pump house casing for pumping water to be injected through the primary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

2. The well system of claim **1**, wherein the axis is straight.

3. The well system of claim **1**, further comprising a secondary well screen for injecting water into the aquifer system, the secondary well screen oriented along the axis and having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen.

4. The well system of claim **3**, further comprising a dual-packer assembly contained within the pump house casing, the dual-packer assembly comprising:

a first packer for regulating the flow of water from the submersible pump to the primary well screen; and

a second packer for regulating the flow of water from the submersible pump to the secondary well screen.

5. The well system of claim **4**, wherein:

the first packer is a first pneumatic packer; and

the second packer is a second pneumatic packer.

6. The well system of claim **5**, further comprising:

a first air line configured to extend from a first air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer; and

a second air line configured to extend from a second air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer.

7. The well system of claim **4**, further comprising a tertiary well screen for injecting water into the aquifer system, the tertiary well screen oriented along the axis between the first packer and the second packer.

8. The well system of claim **4**, wherein:

the dual-packer assembly further comprises a shroud substantially surrounding the submersible pump; and

the shroud has a plurality of holes.

9. The well system of claim **8**, wherein the dual-packer assembly further comprises centering guides attached to the shroud for centering the submersible pump within the shroud.

10. A telescoping horizontally directionally drilled well system for supplying water from or returning water to a subsurface aquifer system, the well system comprising:

a primary well screen for initially admitting water from or injecting water into the aquifer system, the primary well screen extending substantially non-vertically within the aquifer system and having a substantially uniform cross-sectional area;

a filter pack substantially surrounding and adjacent to the primary well screen;

a pump house casing located upward of the primary well screen and having a substantially uniform cross-sectional area; and

a submersible pump contained within the pump house casing for pumping water admitted or to be injected through the primary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

11. The well system of claim **10**, further comprising a secondary well screen for initially admitting water from or injecting water into the aquifer system, the secondary well screen extending substantially non-vertically within the aquifer system and having a substantially uniform cross-sectional area greater than the cross-sectional area of the primary well screen.

12. The well system of claim **11**, further comprising a dual-packer assembly contained within the pump house casing, the dual-packer assembly comprising:

a first packer for regulating the flow of water with respect to the primary well screen; and

a second packer for regulating the flow of water with respect to the secondary well screen.

13. The well system of claim **12**, wherein:

the first packer is a first pneumatic packer; and

the second packer is a second pneumatic packer.

14. The well system of claim **13**, further comprising:

a first air line configured to extend from a first air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer; and

a second air line configured to extend from a second air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer.

15. The well system of claim **12**, further comprising a tertiary well screen for initially admitting water from or injecting water into the aquifer system, the tertiary well screen extending substantially non-vertically within the aquifer system and located between the first packer and the second packer.

16. The well system of claim **12**, wherein:

the dual-packer assembly further comprises a shroud substantially surrounding the submersible pump; and

the shroud has a plurality of holes.

17. The well system of claim **16**, wherein the dual-packer assembly further comprises centering guides attached to the shroud for centering the submersible pump within the shroud.

18. A telescoping slant well system for supplying water from or returning water to a subsurface aquifer system, the well system comprising:

a primary well screen for admitting water from or injecting water into the aquifer system, the primary well screen oriented along an axis angled less than ninety degrees below horizontal and having a substantially uniform cross-sectional area;

a secondary well screen for admitting water from or injecting water into the aquifer system, the secondary well screen oriented along the axis and having a substantially uniform cross-sectional area;

a filter pack substantially surrounding and adjacent to the primary well screen and the secondary well screen;

a pump house casing oriented along the axis, upward of the primary well screen, and having a substantially uniform cross-sectional area;

a submersible pump contained within the pump house casing for pumping water admitted or to be injected through the primary well screen; and

a dual-packer assembly contained within the pump house casing, the dual-packer assembly comprising

a first packer for regulating the flow of water with respect to the primary well screen; and

a second packer for regulating the flow of water with respect to the secondary well screen;

wherein the cross-sectional area of the pump house casing is greater than the cross-sectional area of the primary well screen.

19. The well system of claim **18**, wherein:

the first packer is a first pneumatic packer; and

the second packer is a second pneumatic packer.

20. The well system of claim **19**, further comprising:

a first air line configured to extend from a first air pump to the first pneumatic packer for inflating and deflating the first pneumatic packer; and a second air line configured to extend from a second air pump to the second pneumatic packer for inflating and deflating the second pneumatic packer.

21. The well system of claim **18**, further comprising a tertiary well screen for admitting water from or injecting water into the aquifer system, the tertiary well screen oriented along the axis between the first packer and the second packer.

22. The well system of claim **18**, wherein:

the dual-packer assembly further comprises a shroud substantially surrounding the submersible pump; and

the shroud has a plurality of holes.

23. The well system of claim **22**, wherein the dual-packer assembly further comprises centering guides attached to the shroud for centering the submersible pump within the shroud.

24. A method of constructing a well system for supplying water from or returning water to an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends substantially non-vertically beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings;

placing a well screen within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings, the well screen comprising a first portion having a substantially uniform cross-sectional area and a second portion having a substantially uniform cross-sectional area greater than the cross-sectional area of the first portion; and

placing a filter pack in the space between the well screen and the one or more temporary casings.

25. The method of claim **24**, further comprising the step of withdrawing the one or more temporary casings.

26. The method of claim **24**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

27. The method of claim **24**, wherein, in the step of placing a telescoping plurality of casings, the telescoping plurality of casings further comprises a pump house casing.

28. The method of claim **27**, wherein:

the pump house casing has an upward end and a downward end; and

the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing.

29. The method of claim **28**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

30. The method of claim **24**, wherein the step of placing the filter pack comprises the steps of:

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings; and

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings.

31. The method of claim **30**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

32. The method of claim **31**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

33. The method of claim **30**, wherein the step of placing the filter pack further comprises the steps of:

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer; and

pumping water through the water pipe to settle the filter pack material.

34. The method of claim **33**, further comprising the step of withdrawing the packer assembly and the one or more tremie pipes.

35. The method of claim **34**, further comprising the step of withdrawing the one or more temporary casings;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

36. A method of constructing a well system for supplying water from returning water to an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends substantially non-vertically beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings and a pump house casing, the pump house casing having an upward end and a downward end;

placing a well screen within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings and so that the well screen extends upwardly through the downward end of the pump house casing; and

placing a filter pack in the space between the well screen and the one or more temporary casings.

37. The method of claim **36**, further comprising the step of withdrawing the one or more temporary casings.

38. The method of claim **36**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

39. The method of claim **36**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

40. The method of claim **36**, wherein the step of placing the filter pack comprises the steps of:

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings; and

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings.

41. The method of claim **40**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

42. The method of claim **41**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

43. The method of claim **40**, wherein the step of placing the filter pack further comprises the steps of:

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer; and pumping water through the water pipe to settle the filter pack material.

44. The method of claim **43**, further comprising the step of withdrawing the packer assembly and the one or more tremie pipes.

45. The method of claim **44**, further comprising the step of withdrawing the one or more temporary casings;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

46. A method of constructing a well system for supplying water from or returning water to an aquifer, the method comprising the steps of:

placing a telescoping plurality of casings below a land surface so that the telescoping plurality of casings extends substantially non-vertically to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings;

placing a well screen within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings;

placing a filter pack in the space between the well screen and the one or more temporary casings; and

withdrawing the one or more temporary casings;

wherein the step of placing the filter pack comprises the steps of

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings,

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings,

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer,

pumping water through the water pipe to settle the filter pack material, and

withdrawing the packer assembly and the one or more tremie pipes;

wherein the steps of withdrawing the one or more temporary casings and withdrawing the packer assembly and the one or more tremie pipes are gradually performed as the steps of pumping and settling filter pack material are performed, so that the filter pack is placed and settled along the length of the well screen.

47. The method of claim **46**, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

48. The method of claim **46**, wherein, in the step of placing a telescoping plurality of casings, the telescoping plurality of casings further comprises a pump house casing.

49. The method of claim **48**, wherein:

the pump house casing has an upward end and a downward end; and

the step of placing the well screen comprises placing the well screen so that the well screen extends upwardly through the downward end of the pump house casing.

50. The method of claim **49**, further comprising the step of fitting the downward end of the pump house casing with a seal, the well screen extending upwardly through the seal.

51. The method of claim **46**, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

52. The method of claim **51**, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

* * * * *

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	

Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76.
This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Inventor Information:

Inventor 1 Remove
Legal Name

Prefix	**Given Name**	**Middle Name**	**Family Name**	**Suffix**
	Dennis	E.	Williams	

Residence Information (Select One) ◉ US Residency ◯ Non US Residency ◯ Active US Military Service

City	Altadena	**State/Province**	CA	**Country of Residence** i	US

Mailing Address of Inventor:

Address 1	P.O. Box 220		
Address 2			
City	Claremont	**State/Province**	CA
Postal Code	91711	**Country** i	US

All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the **Add** button. Add

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).

☐ **An Address is being provided for the correspondence Information of this application.**

Customer Number	113671	
Email Address	LAIPDocketing@sheppardmullin.com	Add Email Remove Email

Application Information:

Title of the Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS		
Attorney Docket Number	0JFM-102455	**Small Entity Status Claimed**	☒
Application Type	Provisional		
Subject Matter	Utility		
Total Number of Drawing Sheets (if any)	3	**Suggested Figure for Publication (if any)**	

Filing By Reference :

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	

Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

Only complete this section when filing an application by reference under 35 U.S.C. 111(c) and 37 CFR 1.57(a). Do not complete this section if application papers including a specification and any drawings are being filed. Any domestic benefit or foreign priority information must be provided in the appropriate section(s) below (i.e., "Domestic Benefit/National Stage Information" and "Foreign Priority Information").

For the purposes of a filing date under 37 CFR 1.53(b), the description and any drawings of the present application are replaced by this reference to the previously filed application, subject to conditions and requirements of 37 CFR 1.57(a).

Application number of the previously filed application	Filing date (YYYY-MM-DD)	Intellectual Property Authority or Country i

Publication Information:

☐	Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐	**Request Not to Publish.** I hereby request that the attached application not be published under 35 U.S.C. 122(b) and certify that the invention disclosed in the attached application **has not and will not** be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32).
Either enter Customer Number or complete the Representative Name section below. If both sections are completed the customer Number will be used for the Representative Information during processing.

Please Select One:	◉ Customer Number	○ US Patent Practitioner	○ Limited Recognition (37 CFR 11.9)
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Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78.
When referring to the current application, please leave the application number blank.

Prior Application Status			Remove
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)

Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the **Add** button. Add

Foreign Priority Information:

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	
Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS	

This section allows for the applicant to claim priority to a foreign application. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(d). When priority is claimed to a foreign application that is eligible for retrieval under the priority document exchange program (PDX) i the information will be used by the Office to automatically attempt retrieval pursuant to 37 CFR 1.55(h)(1) and (2). Under the PDX program, applicant bears the ultimate responsibility for ensuring that a copy of the foreign application is received by the Office from the participating foreign intellectual property office, or a certified copy of the foreign priority application is filed, within the time period specified in 37 CFR 1.55(g)(1).

			Remove
Application Number	Country i	Filing Date (YYYY-MM-DD)	Access Code i (if applicable)

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Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications

☐ This application (1) claims priority to or the benefit of an application filed before March 16, 2013 and (2) also contains, or contained at any time, a claim to a claimed invention that has an effective filing date on or after March 16, 2013.
NOTE: By providing this statement under 37 CFR 1.55 or 1.78, this application, with a filing date on or after March 16, 2013, will be examined under the first inventor to file provisions of the AIA.

Authorization to Permit Access:

☐ Authorization to Permit Access to the Instant Application by the Participating Offices

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	
Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS	

If checked, the undersigned hereby grants the USPTO authority to provide the European Patent Office (EPO), the Japan Patent Office (JPO), the Korean Intellectual Property Office (KIPO), the World Intellectual Property Office (WIPO), and any other intellectual property offices in which a foreign application claiming priority to the instant patent application is filed access to the instant patent application. See 37 CFR 1.14(c) and (h). This box should not be checked if the applicant does not wish the EPO, JPO, KIPO, WIPO, or other intellectual property office in which a foreign application claiming priority to the instant patent application is filed to have access to the instant patent application.

In accordance with 37 CFR 1.14(h)(3), access will be provided to a copy of the instant patent application with respect to: 1) the instant patent application-as-filed; 2) any foreign application to which the instant patent application claims priority under 35 U.S.C. 119(a)-(d) if a copy of the foreign application that satisfies the certified copy requirement of 37 CFR 1.55 has been filed in the instant patent application; and 3) any U.S. application-as-filed from which benefit is sought in the instant patent application.

In accordance with 37 CFR 1.14(c), access may be provided to information concerning the date of filing this Authorization.

Applicant Information:

Providing assignment information in this section does not substitute for compliance with any requirement of part 3 of Title 37 of CFR to have an assignment recorded by the Office.

Applicant 1 Remove

If the applicant is the inventor (or the remaining joint inventor or inventors under 37 CFR 1.45), this section should not be completed. The information to be provided in this section is the name and address of the legal representative who is the applicant under 37 CFR 1.43; or the name and address of the assignee, person to whom the inventor is under an obligation to assign the invention, or person who otherwise shows sufficient proprietary interest in the matter who is the applicant under 37 CFR 1.46. If the applicant is an applicant under 37 CFR 1.46 (assignee, person to whom the inventor is obligated to assign, or person who otherwise shows sufficient proprietary interest) together with one or more joint inventors, then the joint inventor or inventors who are also the applicant should be identified in this section.

Clear

- (●) Assignee
- ( ) Legal Representative under 35 U.S.C. 117
- ( ) Joint Inventor
- ( ) Person to whom the inventor is obligated to assign.
- ( ) Person who shows sufficient proprietary interest

If applicant is the legal representative, indicate the authority to file the patent application, the inventor is:

Name of the Deceased or Legally Incapacitated Inventor :

If the Applicant is an Organization check here. ☒

Organization Name	GEOSCIENCE Support Services, Inc.		
Mailing Address Information:			
Address 1	P.O. Box 220		
Address 2			
City	Claremont	**State/Province**	CA
Country i	US	Postal Code	91711
Phone Number		Fax Number	

Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	

Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

Email Address	

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First Name	Darren	Last Name	Franklin	Registration Number	51701

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Application Data Sheet 37 CFR 1.76	Attorney Docket Number	0JFM-102455
	Application Number	
Title of Invention	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS	

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PROVISIONAL APPLICATION FOR PATENT COVER SHEET – Page 1 of 2

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. ______________________

INVENTOR(S)

Given Name (first and middle [if any])	Family Name or Surname	Residence (City and either State or Foreign Country)
Dennis E.	Williams	Altadena, CA

Additional inventors are being named on the ______ separately numbered sheets attached hereto.

TITLE OF THE INVENTION (500 characters max):

HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

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ENCLOSED APPLICATION PARTS (*check all that apply*)

☑ Application Data Sheet. See 37 CFR 1.76.
☐ CD(s), Number of CDs ______
☑ Drawing(s) *Number of Sheets* 3
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☑ Specification (e.g., description of the invention) *Number of Pages* 12

Fees Due: Filing Fee of $260 ($130 for small entity) ($65 for micro entity). If the specification and drawings exceed 100 sheets of paper, an application size fee is also due, which is $400 ($200 for small entity) ($100 for micro entity) for each additional 50 sheets or fraction thereof. See 35 U.S.C. 41(a)(1)(G) and 37 CFR 1.16(s).

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SIGNATURE /Darren M. Franklin/ DATE 5-7-2015

TYPED OR PRINTED NAME Darren M. Franklin REGISTRATION NO. 51,701
(*if appropriate*)

TELEPHONE 213 620-1780 DOCKET NUMBER 0JFM-102455

PROVISIONAL APPLICATION

of

DENNIS E. WILLIAMS

for

UNITED STATES LETTERS PATENT

on

HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

Attorney Docket No.: 0JFM-102455

Sheets of Drawings: Three (3)

Attorneys

SHEPPARD, MULLIN, RICHTER & HAMPTON LLP
333 South Hope Street, 43rd Floor
Los Angeles, California 90071-1422
Telephone: (213) 620-1780
Facsimile: (213) 620-1398

HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

FIELD OF THE INVENTION

The invention relates generally to the field of subsurface water sources to desalination plants (i.e. desalination feedwater supplies). Specifically, the invention relates to a subsurface water supply utilizing a single slant well, an array of slant wells, or multiple arrays of slant wells to supply water from near shore or subsea aquifers to desalination plants.

BACKGROUND OF THE INVENTION

Water developers in California and other coastal communities throughout the world are increasingly considering seawater desalination as a potential source of water for municipal and industrial supply. Limited ground water supplies in the coastal areas, poor inland ground water quality, and decreasing reliability of imported water have made seawater desalination a viable consideration. This has been made even more viable through more cost effective and efficient subsurface intake systems and water treatment technologies. Subsurface slant well feedwater systems produce water from near shore and offshore subsurface aquifer systems. One of the primary requirements for a successful slant well beneath the ocean is the ability to place an artificial filter pack around the screened portion of the well.

Slant well drilling is included in the practice of drilling non-vertical wells. Non-vertical wells are typically used in the petroleum industry and are also known as horizontally directionally drilled wells (HDD wells). Slant wells are also used in other applications, such as drilling beneath roadways or rivers in order to provide conduits for facilities. Slant well desalination subsurface intake systems present significant advantages over traditional open water desalination plant intakes. These advantages include avoidance of entrainment and impingement impacts to marine life, reduction or elimination of costly reverse osmosis pretreatment, and reduction or elimination of permanent visual impacts. Slant well systems are buried systems (i.e.

there are little or no visual impacts on the surface), as the wells and connecting pipelines are typically completed below the land surface.

In the past, slant well technology has not been successfully applied to subsea construction of desalination feedwater supplies, as the well screen slots have become clogged during pumping. Once the well screen slot openings are clogged, it becomes difficult or impossible to continue to pump water. Accordingly, there is a need for a reliable slant well system that is able to supply water from near-shore or subsea aquifers to a desalination plant without becoming clogged with fine-grained materials (e.g., fine sands and silts) over time. The present invention satisfies these needs and provides further related advantages, especially with regard to regulation of feedwater salinity.

SUMMARY OF THE INVENTION

The present invention may be embodied in certain systems and methods for obtaining a subsurface feedwater supply to a desalination plant through a single slant well or a well field of slant wells. The process involves construction of a system of shallow angled[1] wells (slant wells) which obtain a desalination feedwater supply from permeable aquifer systems near and/or beneath a saline water source (i.e. ocean, sea or salty inland lake). The slant wells induce recharge through the floor of the ocean, sea or inland lake due to the hydraulic head difference between the slant well pumping level and the level of the ocean, sea or lake. Slant wells also receive recharge from horizontal flow in subsea and near shore aquifers. As the supply source is relatively constant, the water supply to a slant well system generally provides a long-term sustainable water source.

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[1] Typically, slant wells are constructed from a few degrees to a few tens of degrees below horizontal. However, the slant well angles may vary from zero to ninety degrees below horizontal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a cross section of an angled well producing water from aquifers near or beneath the ocean floor (i.e. subsea aquifers) delivering feed water to a seawater reverse osmosis (SWRO) desalination plant, in accordance with an embodiment of the present disclosure.

FIGURE 2 shows a portion of an angled well screen, in accordance with an embodiment of the present disclosure, consisting of a pipe with perforations in the lower portion.

FIGURE 3 shows a cross section of a well screen surrounded by an artificial filter pack contained in a mesh or other appropriate containment material. In this manner, the well screen (full or half moon pattern) is pre packed prior to insertion inside the temporary casings.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The invention is generally embodied in a slant or HDD well, or system of slant or HDD wells, that produces water from permeable deposits near or beneath saline water bodies (e.g., oceans, seas, or inland lakes) or injects concentrate return into deposits beneath saline water bodies. The invention can provide a long-term, sustainable feedwater supply for a desalination plant with virtually unlimited recharge potential.

FIGURE 1 shows a slant well **1** drawing feed water from a subsurface aquifer **2**. Water **3** from permeable aquifer materials comprising the subsea aquifer enters the slant well screen **4** recharged from the overlying ocean **5** as well as horizontal flow **6.** The slant well **1,** receiving recharge from sources **3** and **6,** pumps to the desalination plant **7** through an appropriate pipeline.

Similar slant well systems are described in U.S. Patent Nos. 8,056,629 and 8,479,815, which are incorporated by reference as if fully set forth herein. Although the slant well systems disclosed in U.S. Patent Nos. 8,056,629 and 8,479,815 are a vast improvement over previous slant well systems, certain limitations exist, particularly with reference to settlement of filter packs leading to problems of fine-grained sediment entering the slant well 1.

During the lifetime of artificially filter-packed vertical wells, the filter material placed in the annular space between the borehole wall and the well screen tends to lose volume due to compaction and settlement over time. To refill the filter pack, gravel feed pipes are placed in the annular space between the well screen and borehole wall. This allows for periodic topping up the filter pack preventing migration of fine-grained aquifer materials into the well during pumping. In vertical wells the gravitational forces acting downward are parallel to the vertical axis of the well and the filter pack completely surrounds the well screen.

However, in angled wells, such as those discussed here, which vary from a few degrees to a few tens of degrees below horizontal, gravitational forces also act vertically but do so throughout the entire well screen length. Due to the angled wells' unique method of construction, there is no filter pack reservoir other than the volume of filter material resting above the top of the well screen pipe. Over time, consolidation of this overlying filter material may result in the pack settling to the point that the top of the well screen is exposed directly to fine-grained aquifer materials. If the angled well screen is perforated throughout the entire circumference of the well screen pipe, settlement of the pack will expose well perforations directly to aquifer materials which could result in fine-grained aquifer materials entering the well screen pipe and, potentially, catastrophic well failure.

To prevent this from happening, the angled well screen pipe can be perforated only in the lower portion allowing some filter pack material to remain above the perforations (in the annular space between the top of the perforations and the borehole wall) acting as a reservoir. These partial perforations (or half-moon pattern) allow for some vertical settlement of the filter pack over time but still provide a reservoir to prevent the well screen from directly contacting the aquifer. In other words, the half-moon design creates a built in filter pack reservoir for every lineal foot of well screen length which allows for filter pack settlement without compromising the well's ability to stabilize the aquifer.

FIGURE 2 is a cross section of a portion of a slant well screen with a half-moon perforation pattern **8,** in accordance with an embodiment of the present disclosure. In this example, an 18 in. diameter pipe is perforated in the lower 57% of the pipe's circumference[2]. For this diameter pipe, a 100% perforation pattern would consist of 14 perforations. The number of perforations may vary with pipe diameter as well as perforation length.

Table 1 shows perforation percentages for exemplary 14 in. and 18 in. well screen pipes. The percentages shown in Table 1 are relative to a full circumference perforated screen. To arrive at these figures, it was assumed that the outer diameter of a 14 in. ID screen is 14 inches + 2 x ¼ in. wall + 2 x ¼ in. collars + 1/8 in. weld bead, which is approximately 15 1/8 inches. The circumference is then equal to 47.4925 inches. Each perforation is 3 in. long with 1.75 inch spaces between louvers. So for a 14 in. screen, the sum of 10 x 3 in. louvers + 10 x 1.75 in. spaces = 47.5 in, which corresponds to a 100% perforation percentage of the outer circumference of the screen. Similarly, it was assumed that the outer diameter of an 18 inch ID well screen is approximately 21 inches, which corresponds to an outer circumference of about 66 inches. If each perforation is 3 inches long with a 1.75 inch space between louvers, 14 perforations x 3 inches/louver + 14 x 1.75 inch spaces = 66.5 inches, or 100% perforation coverage.

[2] These are percentages of the circumference perforated relative to 100% of the circumference perforated. These percentages do not represent well screen open area.

14 in ID Well Screen							
No. of perforations per circumference	2	4	6	8	10		
% of diameter perforated	20	40	60	80	100		
18 in ID Well Screen							
No. of perforations per circumference	2	4	6	8	10	12	14
% of diameter perforated	14	29	43	57	71	86	100

Table 1. Percentage of pipe circumference vs. no of perforations for 14 in. and 18 in. well screen

The top portion of the figure (2a) shows a plan view of the 57% half-moon pattern while the lower portion (2b) shows a cross section. In Figure 2b the filter pack reservoir is shown as well as the settlement of the pack. The perforated pipe forming the angled well screen **9** is placed within the angled borehole **10**. In the example of Figure 2, the artificial filter pack **11** placed in the annular space between the angled well borehole **10** and the perforated pipe **9** has settled to the level **12.** A filter pack reservoir **13** exists above the top of the perforations **8** which provides a filter pack reservoir preventing migration of fine-grained aquifer materials **14** into the angled well **9.** In this example, the total available filter pack reservoir is shown as **15.** As can be seen, even with the settlement of the pack below the top of the well screen pipe, there is sufficient filter material above the well screen perforations to prevent migration of fine-grained materials into the well.

FIGURE 3 is a cross section of a portion of a slant well screen with a half-moon perforation pattern **16,** in accordance with an embodiment of the present disclosure. Surrounding the well screen is an artificial filter pack contained between the well screen and a containing mesh or other appropriate containment material **17.** Loose artificial filter pack material **18** is placed between the well screen and the mesh containment material prior to insertion inside the temporary casings **19**.

WHAT IS CLAIMED IS:

1. An angled well screen configuration which allows for a filter pack reservoir to be maintained above the top of the well screen pipe to prevent migration of fine-grained aquifer materials from entering the well if settlement of the pack falls below the top of the pipe.
2. Perforation of the lowermost portion of an angled well screen pipe allows for a filter pack reservoir to occur above the top of the well screen perforations and extending to the borehole wall (or the uppermost level of the artificial pack). This design allows for vertical settlement of the artificial filter pack over time without compromising the ability of the well to stabilize fine-sand aquifer materials.
3. A slant well feedwater supply system for supplying water from a subsurface aquifer system, the feed-water supply system comprising:

    a primary well screen for admitting water from the aquifer system, the primary well screen oriented along an axis angle less than or equal to ninety degrees below horizontal; and

    a filter pack substantially surrounding and adjacent to the primary well screen, wherein

    the primary well screen comprises

    an upper portion that is substantially free of perforations; and

    a lower portion that comprises a plurality of perforations for admitting water from the aquifer system.
4. The slant well feedwater supply system of claim 3, wherein the filter pack is pumped into the space surrounding the well screen by one or more tremie pipes.
5. The slant well feedwater supply system of claim 3, wherein the filter pack is secured around the primary well screen by a containment material.
6. A method of constructing a slant well feedwater supply system for supplying water from an aquifer, the method comprising the steps of:

placing a telescoping plurality of casing below a land surface so that the telescoping plurality of casing extends along an axis angled below horizontal to beneath a water body, wherein the telescoping plurality of casings comprises one or more temporary casings;

placing a well screen along the axis within the one or more temporary casings so that a space is formed between the well screen and the one or more temporary casings, the well screen comprising

an upper portion that is substantially free of perforations, and

a lower portion comprising a plurality of perforations for admitting water; and

placing a filter pack in the space between the well screen and the one or more temporary casings.

7. The method of claim 6, further comprising the step of withdrawing the one or more temporary casings.

8. The method of claim 6, wherein the step of placing the well screen comprises the step of centering the well screen within the one or more temporary casings using centering guides.

9. The method of claim 6, wherein the step of placing the filter pack comprises the steps of:

extending one or more tremie pipes to the space between the well screen and the one or more temporary casings; and

pumping filter pack material under pressure through the one or more tremie pipes into the space between the well screen and the one or more temporary casings.

10. The method of claim 9, wherein the step of extending the one or more tremie pipes comprises the step of positioning the one or more tremie pipes within the one or more temporary casings using tremie pipe guides.

11. The method of claim 10, wherein:

the one or more tremie pipes consist of three tremie pipes; and

the step of positioning the tremie pipes comprises spacing the tremie pipes uniformly about the well screen.

12. The method of claim 10, wherein the step of placing the filter pack further comprises the steps of:

placing a packer assembly within the well screen, the packer assembly comprising a packer and a water pipe extending through a hole in the packer; and

pumping water through the water pipe to settle the filter pack material.

13. The method of claim 6, wherein the step of placing a filter pack in the space between the well screen and the one or more temporary cases comprises placing a pre-pack filter around the well screen before placing the well screen within the one or more temporary casings.

ABSTRACT

Systems and methods are disclosed for supplying water to a desalination plant from a subsurface feedwater supply using one or more slant or horizontally directionally drilled ("HDD") wells. In particular embodiments, angled well screen pipes are perforated only on a lower portion of the pipes, allowing some filter pack material to remain above the perforations (in the annular space between the top of the perforations and the borehole wall) acting as a reservoir. These partial perforations (or half-moon pattern) allow for some vertical settlement of the filter pack over time but still provide a reservoir to prevent the well screen from directly contacting the aquifer. Artificial filter pack can be placed using conventional system of tremie pipes or pre-packed prior to insertion inside the temporary casings.

Figure 1

Angled Well Pumping from SubSea Aquifer

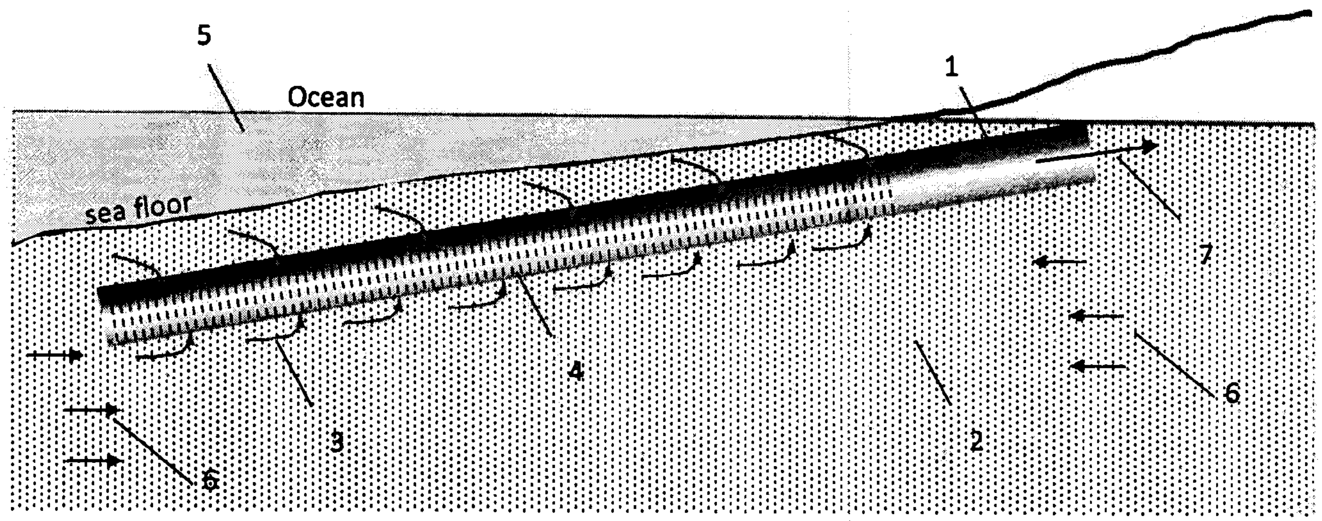


Figure 2

Half Moon Well Screen Pattern with 8/14 (57%) of Circumference Perforated

(Example for 18 in. Well Screen)

100% of circumference perforated would consist of 14 perforations

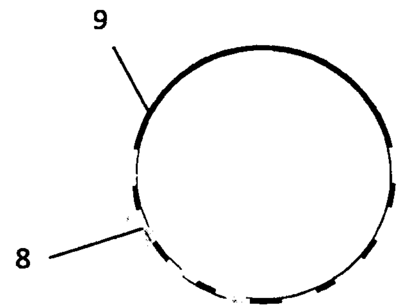


Fig. 2a Plan view of well screen showing half moon pattern 8 perforations per circumference in lower portion of screen

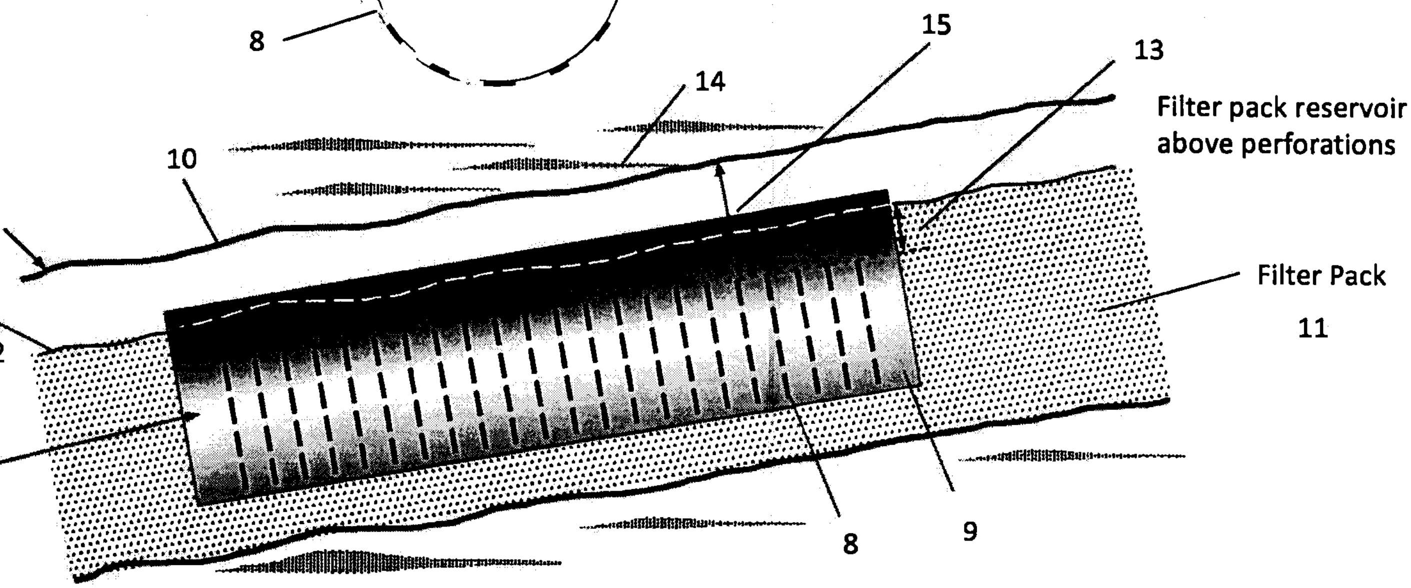
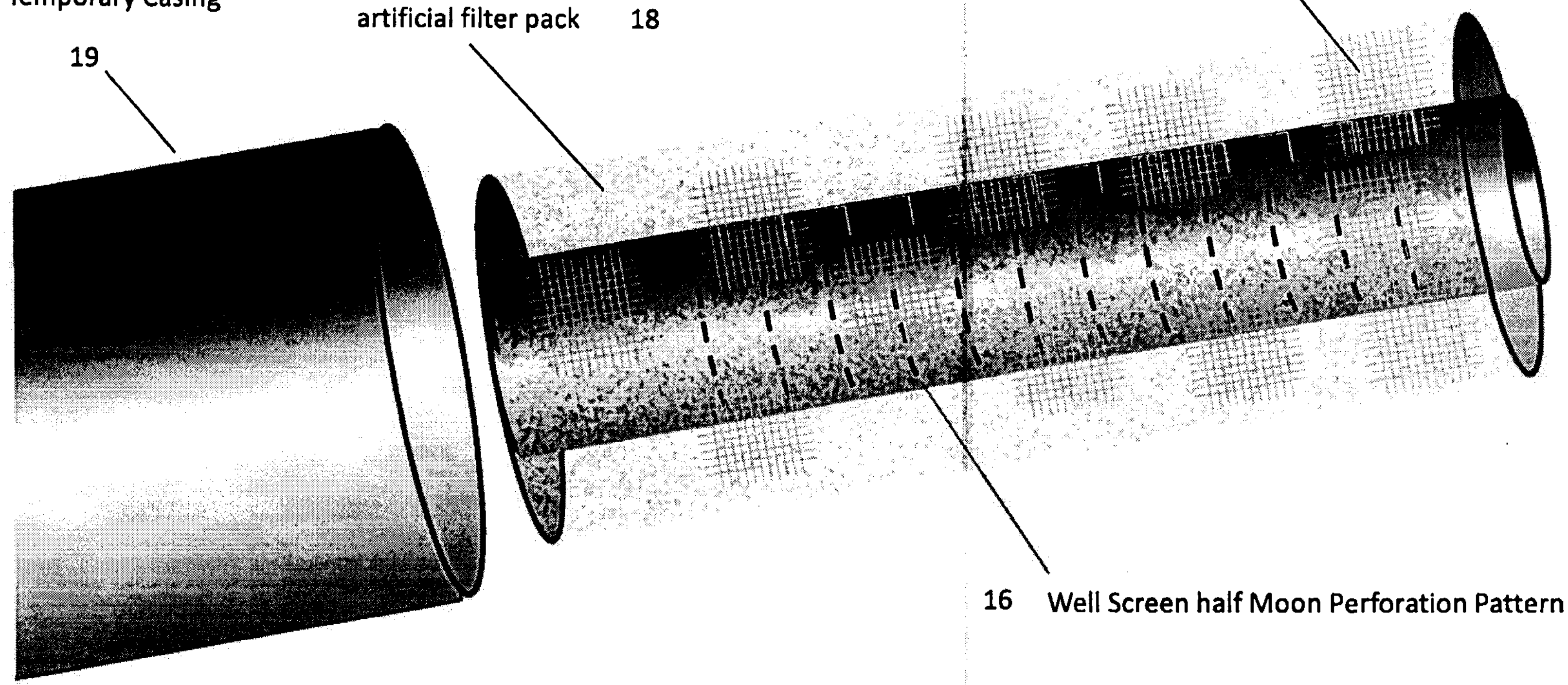


Fig. 2b Cross section view of angled well screen with half moon pattern (lower 57% perforated, 8 perforations/circumference)

Half Moon Screen Design with Pre-Packed Filter

Figure 3



Electronic Patent Application Fee Transmittal

Application Number:	
Filing Date:	
Title of Invention:	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS
First Named Inventor/Applicant Name:	Dennis E. Williams
Filer:	Darren M. Franklin/Betty Rodriguez
Attorney Docket Number:	0JFM-102455

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Description	Fee Code	Quantity	Amount	Sub-Total in USD($)
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EFS ID:	22286809
Application Number:	62158382
International Application Number:	
Confirmation Number:	5689
Title of Invention:	HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS
First Named Inventor/Applicant Name:	Dennis E. Williams
Customer Number:	113671
Filer:	Darren M. Franklin/Betty Rodriguez
Filer Authorized By:	Darren M. Franklin
Attorney Docket Number:	0JFM-102455
Receipt Date:	07-MAY-2015
Filing Date:	
Time Stamp:	17:48:13
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
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Claims	11	13
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APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
62/158,382	05/07/2015		130	0JFM-102455		

CONFIRMATION NO. 5689

FILING RECEIPT

OC000000075240096

113671
Sheppard Mullin Richter & Hampton LLP
333 S. Hope Street
Forty-Third Floor
Los Angeles, CA 90071

Date Mailed: 05/19/2015

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Inventor(s)

Dennis E. Williams, Altadena, CA;

Applicant(s)

GEOSCIENCE Support Services, Inc., Claremont, CA;

Power of Attorney:
Darren Franklin--51701

If Required, Foreign Filing License Granted: 05/18/2015

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 62/158,382**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

HALF-MOON WELL SCREEN DESIGN FOR ANGLED WELLS

Statement under 37 CFR 1.55 or 1.78 for AIA (First Inventor to File) Transition Applications: No

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